# ELEMENTARY ELECTRICITY AND MAGNETISM

JACKSON

Wm George Clark
S. P. S.

# ELECTRICITY AND MAGNETISM

## AND THEIR APPLICATIONS

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# AN
# ELEMENTARY BOOK
# ON
# Electricity and Magnetism
# AND THEIR APPLICATIONS

A TEXT-BOOK FOR MANUAL TRAINING SCHOOLS AND HIGH SCHOOLS, AND A MANUAL FOR ARTISANS, APPRENTICES, AND HOME READERS

BY

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# PREFACE

While this book is more especially intended for an elementary textbook, it is believed that it will be interesting to all readers who have a taste for science and that it will prove a useful manual for apprentices and artisans. Every effort has been exerted to make it clear, forceful, and of strict scientific accuracy, though it is written in reasonably colloquial language.

The book is essentially the outcome of the authors' belief that elementary physical science may properly be — nay, should only be — taught in an atmosphere filled with the inspiration gathered from an interest in every-day occurrences. (Physics is a science of our daily life and experiences.) If this is a very ordinary belief, it surely is one much honored in the breach.

The masters of the theory and of the practice of teaching, from the sixteenth century to the present, have held that all intellectual acquirement must come to us through the senses, and that we can reason upon the abstract only by reaching out from the concrete which is already grasped. Moreover, elementary instruction should be made interesting to the pupils, and the matter should be presented in an order and in a manner which will result in the readiest and most complete assimilation.

These principles of good teaching point to an overthrow of the traditional academic order and abstract presentation in elementary instruction in physical science and the substitution therefor of a rational presentation of applied science. The rational order of instruction here is one which follows very nearly in the same sequence as the order of discoveries and industrial applications. Industrial development is usually along the line of march from the simple to the complex, and this path must, in the main, be followed to stimulate the most effective assimilation by the pupil.

The writers have herein attempted to treat a division of physical science in the manner suggested. The order of the book is from the simple to the complex, and the pages keep in reasonably close touch with the more or less common experiences of the pupils for whom the book is intended, or with the knowledge which comes by reasoning directly from those experiences.

The treatment has been planned with the purpose of introducing, at desirable places in the regular text, elementary explanations of certain scientific principles which are not a part of the immediate subject of the book; which cannot be assumed to be already a part of the pupil's knowledge; but which must be understood by the pupil before he can properly grasp the subject-matter in hand. The plan pursued is unusual, as it places the statement of these principles at the points of their application instead of in the introductory part of the book; but it is believed to be a proper plan for an elementary book, since it encourages the pupil to base all of his reasoning directly upon foundation knowledge.

Extended use of analogies has been made throughout the book, but especially in its earlier part. Definitions of important units are often left, in the earlier part of the book, to be inferred from them; but in all such cases the exact definitions are found on later pages. This accords with the usual order of acquiring a knowledge of physical units by children, and should add vigor and zest to the pupil's pursuit of intellectual acquirement. It is the constant desire of the writers to interest the pupil, and to stimulate him to an active inquiry into the principles and laws which underlie physical phenomena, and to bring him to a reasonably vivid physical conception of the characteristics of the phenomena.

It is desirable that suitable laboratory practice shall accompany the use of the book in the schools. This may consist of experimental examinations of electric and magnetic phenomena and the performance of the simpler electrical measurements. The laboratory instruction should be designed to aid the pupil in gaining a livelier conception of the phenomena treated in the book. Small wooden or metal models of essential machine parts and instruments not used in the laboratory may add an element of life and interest to class-room instruction, as well as conduce to clearer conceptions on the part of the pupils. When the time for class-room instruction is limited, well-informed teachers may readily select the portions of the book that are most suitable for their purpose.

The proof of the book was twice read by Principal G. W. Krall, of the St. Louis (Missouri) Manual Training School, and Superintendent F. A. Lowell, of the Rhinelander (Wisconsin) Schools; and a part of it was read by Assistant Professor Fred A. Fish, of the Ohio State University. The authors are in their debt for numerous suggestions which have added to the clearness and accuracy of the treatment. Professor A. C. Scott, of the Rhode Island College of Agriculture and Mechanic Arts (Honorary Fellow in Electrical Engineering at the University of Wisconsin), lent efficient aid while the book was passing through the press, and also made the photographs from which various illustrations were produced. So much care has been given to the preparation of the manuscript and the reading of the proofs that it may be justly hoped that any remaining imperfections are of only minor character. The writers will be grateful to teachers and others for notice of inaccuracies or obscure passages which may be discovered.

THE AUTHORS.

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# ELECTRICITY AND MAGNETISM

## CHAPTER I

### THE NATURE AND PROPERTIES OF ELECTRICITY

**1. Electricity.** — The exact nature of the electricity which makes itself evident in so many ways has never been determined. Many surmises or theories have been advanced, but none have yet been able to fully stand the test of close examination. But by experimental evidence (which has been gathered for decades) we have been able to determine some of the laws which govern the action of electricity, though we do not know its constitution, very much as we have learned the laws of gravitation, though we do not know what "gravity" really is.

The etymology and use of the word "electricity" have developed in parallel with the experimental growth of the science which bears its name. Springing from the Latin name for amber, *electricus* or *electrum*, the adjective **Electrical** comes immediately from the word "electric," which was used in a book published in 1600 by Dr. Gilbert (the great scientist of Queen Elizabeth's reign), to designate the attraction for light bodies like chaff and bits of paper which amber and similar substances exhibit when briskly rubbed. The original discovery of this electrical property (or *property of the amber*) is often attributed to a Greek philosopher (one of the "seven wise men" of Greece) named Thales, who lived about 600 years before the Christian era, and the meagre reports of whose philosophy are thought by some to contain the earliest records of its observation that have come down to us. It is probable, however, that a knowledge of this peculiar property of amber, and possibly of other bodies, was one of the well-guarded secrets of the priesthood of that day.

From the word "electric" also comes the word **Electricity**. Since the day Dr. Gilbert first applied the word "electric" to a particular phenomenon, our knowledge of all the sciences has widened, and with the widening has come an equal advance in the knowledge which was represented to the ancients by that one peculiar property of amber and similar bodies. The term "electricity" is, therefore, not now applied to only one small branch of a great science, but covers a vast field of facts which are supposed to be based on the same underlying causes.

**2. The Nature of Electricity.** — The action of electricity led many experimenters who lived long after Gilbert to the belief that it was a fluid which was not perceptible to their senses. Our own great philosopher and statesman, Benjamin Franklin, assumed it to be a fluid, and bodies which exhibited electrical manifestations were thought by him to contain either more or less than a normal amount of the fluid. A Frenchman named Dufay and an Englishman named Symmer considered electricity to be composed of two fluids which were contained in neutral bodies in equal amounts. When by any means this equality was disturbed in a body, electrical manifestations occurred.

These theories, and a large number similar to them that were promulgated, are now discarded in the light of later scientific knowledge. But the conception of the fluid theory is very useful in giving a clear understanding of some of the phenomena of electricity. It is now generally accepted that the phenomena to which we give the name electricity result from a state of strain or other manifestation in the **Ether.** The ether is a kind of fluid medium that is supposed by scientists to be present everywhere. It must even be supposed to pass through or be contained in solid bodies, as though they were ether sieves, as well as in empty space. Heat and light are supposed to be carried by it from one body to another, as from the sun to the earth, by means of vibrations or waves, much as the energy exerted by a pebble thrown into a pond is carried to the shores by the waves of the water. In like manner electricity is supposed to be waves in the ether or a strain imposed on it. The question of what the ether may really be need not be considered in dealing with the fundamental laws governing the action of electricity.

**3. Static and Current Electricity.** — We will not at this time further discuss the nature of electricity, but will pass on to a consideration of its properties. The study of these properties may be suitably divided into two classes — the first, in which **Static Electricity**, or electricity at rest, is considered; and the second, in which **Current Electricity**, or electricity in motion, is considered. There is no well-defined division between these, and the laws governing the two classes are practically the same.

In general, however, the first class includes the phenomena known by the ancients, where electricity is produced by rubbing or by the influence of one **Electrified** body on another. The second class includes electricity produced by the electric batteries and dynamos which are so well known to-day. The first class is of comparatively small importance and will receive only such attention in the earlier part of this book as is necessary on account of its bearing on the second class.

**4. Positive and Negative Electricity.** — If a rod of sealing-wax, amber, or other resinous substance is rubbed with a dry wool cloth or fur, it immediately gains the property of attracting to itself light bodies, such as pith or bits of paper. After the bits of pith have been in contact with the rubbed body for a short time, they usually fly off as if repelled, and they also seem to repel each other. The rubbed body when in the condition produced by the rubbing may be found by proper examination to be covered with an apparent layer of electricity, which is called a **Charge**, and the body is said to be **Charged** with electricity. The pith balls which touch the rubbed body become covered with a similar layer, and are also said to be charged.

If a glass rod is rubbed with silk, it will show properties like those of the resinous substances. But, if the glass rod is brought close to the pith balls which have been in contact with and were repelled by the resin rod, it will strongly attract them; and in the same way the resinous rod attracts pith balls which have been charged by contact with the glass.

These experiments seem to prove the existence of two kinds of electricity, which are called vitreous or **Positive** electricity, and resinous or **Negative** electricity, depending on whether they are produced by rubbing glass with silk, or resinous materials with wool. The action of the pith balls also shows that *bodies charged with one kind of electricity repel those charged with the same kind, but attract those charged with the opposite kind.* Charged bodies are also said to be **Excited** or **Electrified.**

Other similar manifestations of electricity may be easily produced. For instance, if a well-dried sheet of paper is laid on a table and briskly rubbed with a rubber eraser or a coat sleeve, it will seem to stick to the table; and when it is slowly raised by one corner, small sparks may be seen to pass between it and the table, if the room is dark.

On dry days it is sometimes possible for a person to gather a charge on his body by shuffling his feet across the carpet. This charge may be sufficient to produce a spark if the finger is presented to a gas fixture or to another person.

Again, if a charged body is held near to the face, a peculiar, tickling sensation may be felt on account of the attraction of the small hairs on the cheeks by the charge.

**5. Positive Charges develop Equal Negative Charges, and vice versa.** — If the wool used to develop a negative charge on the sealing-wax by rubbing is now tested by bringing a charged pith ball near to it, it also is found to be charged, — this charge being positive. In the same way the silk which was used in rubbing the glass may be found to be negatively charged, the charge on the glass having been positive.

These observations are in accordance with an important fact which has been experimentally proved: *that whenever a charge of one kind is developed, an equal charge of the opposite kind is also developed.*

**6. The Character of the Charge on Rubber and Rubbed.** — When two dry bodies of different materials which do not have the power of conducting electricity are rubbed together, they always become charged with opposite kinds of electricity. If one of these bodies is then rubbed with a third material, its charge may be changed. The kind of charge which appears on the body of one material when rubbed with another material depends altogether on the nature of the two materials that are rubbed together. For instance, as we have seen, when glass is rubbed with silk the glass becomes positively charged, and the silk negatively charged. If a stick of sulphur is rubbed with silk, the order is reversed and the silk becomes positively charged, while the sulphur is negatively charged.

Following out an investigation of this kind, it is possible to arrange a table of materials in which they are placed in such an order that when any two materials named in the table are rubbed together, the one that stands earliest in the table will ordinarily become positively charged and the other negatively charged. The following table is so arranged. Its correctness may be easily tested by experiments.

1. Fur.
2. Wool.
3. Some Resinous Substances.
4. Glass.
5. Cotton.
6. Silk.
7. Wood.
8. Metals.
9. Sulphur.
10. Other Resinous Substances.
11. India-rubber.
12. Gutta-percha.

The reason for this difference in materials is not known, and, in fact, slight differences in the constitution or the surface of the materials may cause them to change their relative positions, so that similar tables given in various books do not all agree.

7. **Conductors and Insulators.** — If a piece of metal is held in the hand and rubbed, no apparent charge can be discovered on it. This is because the metal has the power of readily conducting electricity, as it has likewise the power of conducting heat, and the electricity therefore all flows away into the body of the operator, or through his body into the earth. The same thing is true of any of the substances named in the table if they are dampened with water, because water has the power, to a limited degree, of conducting electricity. Consequently, experiments with static electricity cannot be readily made on a damp day or when the materials are damp.

If the metal is fastened in a handle of dry wood or hard rubber and again rubbed, it will then become charged. This is because the wood or hard rubber does not have the power of conducting the electricity to an extent which is in this case appreciable, and the charge of electricity, therefore, cannot escape, but remains on the metal.

Materials which readily conduct electricity are called **Conductors**, and those which either do not conduct it at all or only conduct it in a very small degree are called **Non-conductors** or **Insulators**. Other materials which have the conducting power in an intermediate degree are often called **Partial Conductors.**

The following table gives a list of materials placed approximately in the order of their conducting powers: —

1. Metals.
2. Charcoal and Graphite.
3. Acids.
4. Salty Solutions.
5. Plants and Animals.
6. Pure Water.
7. Various Oils.
8. Dry Wood.
9. Silk.
10. India-rubber.
11. Mica.
12. Shellac.
13. Vulcanite.
14. Paraffine.
15. Porcelain.
16. Glass.
17. Dry Air.

We ordinarily restrict the term "conductor" to the metals. The materials in the table numbered from two to six may be called "partial conductors," and the last eleven materials may be called "insulators." Of all the materials named, dry air may be said to be the only one which has absolutely no conducting power under ordinary conditions, though that of glass, porcelain, etc., is exceedingly small at ordinary temperatures.

The cause of the difference in the conducting powers of the various materials is not known, and will probably not be known until the exact constitution of electricity is determined. When science succeeds in unravelling that mystery, we will probably also learn the exact nature of light, and the cause of the attraction of gravitation, together with the reasons for many other highly important laws the explanations of which are now held among the profound secrets of nature.

By means of the great conducting power, or **Conductivity**, of metals, electricity may be conveyed from place to place. If, for instance, two blocks of metal connected by a wire are mounted on insulators, and if a charge is given to one, a part of the electricity will flow along the wire to the second block and will electrify it. A conductor which is supported on insulators in such a way that electricity cannot escape from it is said to be **Insulated.**

**8. Induced Charges.** — A body may also be charged or electrified by the influence upon it of a charged body. Thus, suppose a brass ball is insulated and charged, and that it is brought near an uncharged but insulated brass ball. The second ball will now be found to be charged, if it is tested by bringing a charged pith ball near to it. A charge which is developed in this manner by the influence of a charged body on a **Neutral** or uncharged one, is said to be developed by **Induction.**

If the brass ball on which the charge is thus **Induced** is carefully examined, its two sides will be found to hold opposite kinds of electricity (Fig. 1). The side of the second ball which is away from the first ball will hold the same kind of electricity as the latter, and the side which is near the first ball will hold the opposite kind. This is in accordance with the law of attraction and repulsion between the different kinds of electricity given in Article 4. For example, if the first ball (*A* in Fig. 1) is positively charged, the side of the second ball (*B* in Fig. 1) which is away from the first will also be positively charged, but the near side will be negatively charged. This is the condition shown in the figure, where the plus or positive sign, +, represents a positive charge, and the minus or negative sign, —, represents a negative charge.

Now, if the second ball is touched by one's finger for an instant when it is very close to the first, the positive charge will immediately flow away into the operator's body on account of the repulsion between the positive charge on the second ball and that which is on the first ball. The negative charge on the second ball will remain on account of the attraction between it and the charge on the first ball. If the second ball is now removed from the influence of the first ball, it will remain negatively charged, the charge spreading all over it. And if the two balls are now brought into contact with each other, the two charges will combine and both balls will become **Neutral**, that is, without any charge.

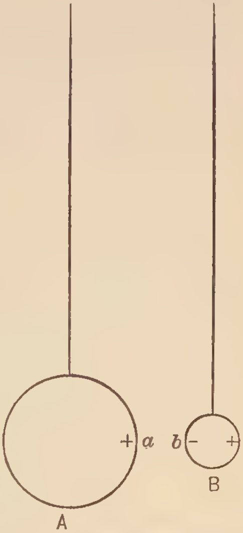

FIG. 1. — Illustration of Electrostatic Induction.

Two brass balls, *A* and *B*, suspended by silk insulating cords.

The experiment described in the last paragraph shows that *each induced charge is equal in quantity to the charge which induces it.* This fact is strictly true, but in many cases the induced charge is divided among several objects which are near a charged body, so that it may be difficult to get complete neutralization in the manner explained. The induced charges are to be found wholly on one body only when it completely surrounds the charged one; but when a body is very much nearer to the charged one than any other bodies, it will receive practically the whole charge.

The object in using brass balls in such experiments is simply to obtain convenient and inexpensive conductors. Any other materials will give similar results, but in the case of poorly conducting bodies it is more difficult to perceive the results on account of the difficulty which such bodies present to the distribution of electricity under the influence of induction.

## QUESTIONS

1. How much is known about the real constitution of electricity?

2. What is the origin of the word "electricity"?

3. What is electricity supposed to be by some scientists?

4. Is there any difference between current and static electricity?

5. What two manifestations of electricity are produced when materials are rubbed?

6. How can the presence of a charge of electricity be shown?

7. Can a charge of one kind of electricity exist alone?

8. What effect have unlike charges of electricity upon each other?

9. Do like charges repel or attract?

10. If a positive charge is developed by rubbing, how large, relatively, will the accompanying negative charge be?

11. If glass is rubbed, will it always take a positive charge, regardless of the material of the rubber?

12. If gutta-percha is rubbed by fur, which will take a positive charge?

13. What precautions must be taken in handling metals in order that they may be charged by rubbing?

14. What is a conductor?

15. What is an insulator?

16. What is the meaning of electrical conductivity?

17. Name some good conductors.

18. Name some partial conductors.

19. Name some ordinary materials that are good insulators.

20. How may electricity be conveyed from one place to another?

21. What effect does a charged conductor have upon an uncharged conductor which is brought near it?

22. What is the meaning of electric induction?

23. How can an induced charge be kept on a body when it is removed from the neighborhood of the body that induced the charge?

24. How will the quantity of an induced charge compare with the quantity of the charge on the inducing body?

25. What kind of electricity will a positively charged ball induce?

26. If an uncharged ball is held near a negatively charged one, what kind of electricity will be evident on the part of the first ball most distant from the charged ball?

27. If a charged body is held in the middle of an otherwise vacant room, where will the induced charges be found?

# CHAPTER II

## ADDITIONAL CHARACTERISTICS OF ELECTRIC CHARGES

**9. Electroscopes.** — The means of detecting a charge thus far mentioned have been through the attraction or repulsion of charged pith balls or other light objects. Various other means may be used, all of which are dependent upon electrical attractions and repulsions for their indications.

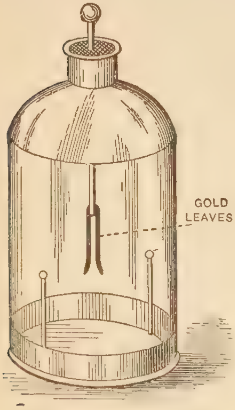

FIG. 2. — Gold-leaf Electroscope.

Devices or instruments for determining the presence of an electric charge are called **Electroscopes**. The simplest one consists of a pith ball (preferably gilded) or other light material, attached to a silk insulating suspending cord. A more sensitive one is made by attaching two narrow strips of ordinary gold leaf, such as can be obtained from any dentist, to the end of a brass rod, and hanging the leaves in a glass bottle to insulate them and protect them from injury (Fig. 2). If a charged body is brought near the top of the rod which is connected to the gold leaves, the rod and leaves are electrified by induction. If the charged body is a rubbed glass rod which is positively charged, as in Figure 3, a negative charge will appear at the top of the conductor and a positive one in the gold leaves.[1] In this case, since the two leaves have charges of the same kind, they will repel each other and separate, as is illustrated in the figure. The gold leaves are so sensitive that they are likely to be torn by the force of their repulsion if a heavily charged body is brought too close.

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[1] Compare the case of the brass balls given in Article 8.

If, while the glass rod is still held near the electroscope, the brass rod of the electroscope is touched by the hand, the positive charge in the leaves will at once flow off into the operator's body on account of the repulsion of the charge on the glass (as was explained in the description of the experiment of the brass balls given above), and the leaves will drop together. Now, if the glass rod is taken away, the negative charge which was retained by the attraction of the charge on the rod will spread all over the electroscope rod and gold leaves, and the leaves will again separate. It can be easily proved that the charge on the gold leaves is now negative by bringing the positively charged glass rod near the top of the electroscope, when the negative charge will be attracted out of the leaves and they will fall together. Or, if a negatively charged rod of sealing-wax is brought near the top of the electroscope, the negative charge in the instrument may all be repelled into the leaves and they will separate farther. With this simple device it is possible to detect a very small charge of electricity and determine its sign.

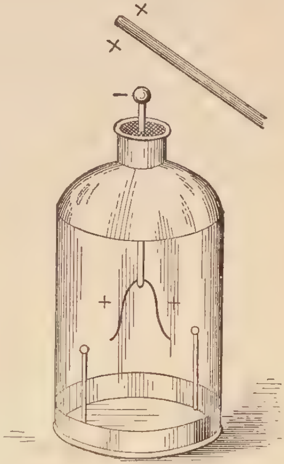

FIG. 3. — Gold-leaf Electroscope charged by Induction.

The electroscope may of course be directly charged by contact with a charged body, but the leaves are likely to be torn by the violence of the action, unless the charge is quite small.

**10. Reason for Attraction between Charged and Light Bodies.** — We are now in position to see the reason for the attraction which rubbed amber, rubbed glass, and other charged bodies have for light objects. Since electric induction acts between any charged body and any other body which is reasonably near, the effect of the charged body on a light object is first to charge it by induction. The positive and negative charges induced on the light object are equal in quantity. One of them is attracted and the other is repelled by the original charge. That which is attracted is nearer the original charge, so that the force of attraction is greater than the force of repulsion. The condition is illustrated in Figure 1, which is here repeated. A positive charge is seen at *a* on the large ball. This induces the negative and positive charges *b* and *c* on the small ball. Since *b* is considerably nearer *a* than is *c*, the attraction between *a* and *b* is materially greater than the repulsion between *a* and *c*. The small ball is therefore attracted toward the large ball. If the balls come in contact, the small ball receives a part of the positive charge belonging to the large one, and they at once separate on account of the repulsion between the two positive charges.

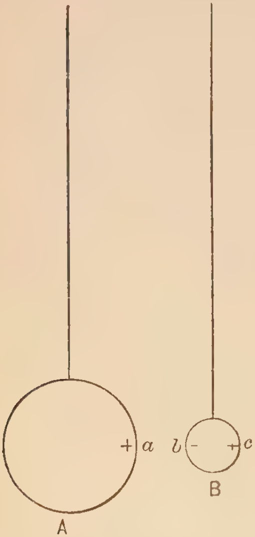

FIG. 1. — Illustration of Electrostatic Induction.

Two brass balls, *A* and *B*, suspended by silk insulating cords.

The attraction or repulsion between a charged body and one which it charges by induction, or between two independently charged ones, always exists, though the pull or push exerted by the charges usually is sufficient to move the bodies only when they are very light.

**11. Force of Attraction or Repulsion.** — The intensity of the attraction or repulsion exerted between any two charged bodies depends upon the product of the quantities of electricity in their charges, their distance apart, and the material which is between them. If they are surrounded by air, the push or pull which is exerted between the two bodies *increases directly with the product of the quantities of electricity which they hold, and decreases directly with the square of the distance between them*, provided the bodies are small compared with that distance. If the two charged bodies are immersed in a liquid, such as water or oil, or are separated by solids, the same law holds true, but the force exerted between them is decreased. The amount of the decrease depends upon the nature of the separating material, and is apparently due to a difficulty met by the attractive force in making its way through the material.

**12. The Coulomb.** — The unit quantity of electricity is called a **Coulomb**, after a French experimenter who lived about the beginning of the nineteenth century. As a rough analogy with the measurement of water or gas, we may say that a coulomb of electricity is the equivalent of a gallon of water or a cubic foot of gas.

The reason that the force exerted between two charged bodies depends upon the product of the two quantities of electricity, is that each coulomb of electricity on one body attracts or repels every coulomb on the other body with a fixed intensity, and therefore the total force of attraction or repulsion depends on the number of coulombs on one body multiplied by the number on the other body.

The intensity in pounds of the push or pull exerted between two charged bodies in air, which has been described in italics in Article 11, may be represented algebraically by the expression

$$20.2 \times 10^{12} \times \frac{q \times q'}{d^2},$$

if $q$ and $q'$ are understood to represent the number of coulombs in the respective charges of electricity, and $d$ is understood to represent the distance between the bodies measured in centimeters. The expression $10^{12}$ stands for one trillion which must be multiplied into the product. (A centimeter is a metric measure of length which is equal to about .39 of an inch.)

*Example.* — Two similarly charged small bodies are at a distance apart of 6 centimeters. One carries a charge of 6 ten-millionths of a coulomb, and the other carries a charge of 9 ten-millionths of a coulomb. What is the intensity of the repulsion exerted between them? *Ans.* .303 pounds.

**13. Electrometers.** — Instruments for determining the quantity of electricity which is held in charge on a body, by measuring its attraction for another charged body, are called **Electrometers.** These instruments are valuable for many purposes, and will receive more attention in later chapters. It is to be borne in mind that electroscopes are instruments for detecting a charge, and electrometers are instruments for measuring the quantity of electricity in a charge.

**14. Static Electricity tends to stay on the Surface of a Conductor.** — One of the peculiar properties of electricity results in a charge always locating on the surface of a charged conductor. We often hear the statement made "that electricity flows only on the surface of a wire." This is entirely untrue. *When electricity flows or moves it apparently passes through the substance of the conductor.* In the case of electricity at rest, however, the condition is different. *When electricity is at rest it never remains in the substance of a body, but stays strictly on the surface.*

It is important that this difference, described in the last paragraph, between the action of *electricity in motion, or current electricity,* and *electricity at rest, or static electricity,* shall be remembered.

Again, a free charge of static electricity not only stays on the surface of a body, but *it tends to stay on the outside surface.* Figure 4 shows this by the position of the pith balls, which are suspended on the inside and outside of a hollow brass cylinder. The cylinder being freely charged, the outside pith balls, which are in contact with it, at once diverge on account of a charge which they receive from the cylinder. This shows that the outer surface of the cylinder is charged. The inner pith balls, which are also in contact with the cylinder, remain entirely inert, showing that *there is no charge on the inner surface.* This is true whether the charge is given to the cylinder from the inside or outside, and is to be expected on account of the known repulsion of like charges or parts of a charge. The different parts of a free charge try to get as far away from each other as possible, and therefore go to the outer surface of a body if its conductivity is sufficient to permit it. A brass cylinder is used in this experiment so that the electricity may readily follow its tendency to move to the outer surface if it should be applied at the inner surface.

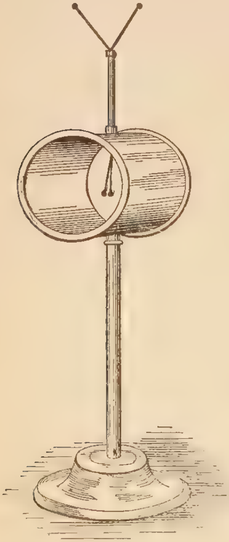

FIG. 4.— Hollow Cylinder with Electrostatic Charge.

It is possible to retain an induced charge on the interior of the cylinder by placing and keeping a charged ball inside of the cylinder. But an equal and opposite induced charge also appears at the same time on the outside of the cylinder. If the charged ball is removed, the induced charges disappear; and if the charged ball is permitted to touch the inside of the cylinder, the induced charges disappear, and all of the charge on the ball at once goes to the outside of the cylinder.

**15. Electric Screens.** — By virtue of the fact that a charge tends to stay on the outer surface of a body, it is possible to entirely screen an object from all electrostatic force by completely surrounding it with a conducting cage. This is done in making electrometers, when it is desirable to screen the working parts of the instrument from the outside electric forces.

## QUESTIONS

1. What is the purpose of the electroscope?

2. In an electroscope, why do the leaves separate when a charged body is brought near its knob?

3. How can the character of a charge be determined by means of an electroscope?

4. How can an electroscope be charged by induction?

5. Why are light bodies drawn to charged bodies?

6. If a light ball is drawn to a charged body will it stick to it? What will happen?

7. Is there any attraction between two heavy bodies, one of which is charged?

8. What effect has the size of two charges upon their mutual attraction or repulsion?

9. What effect has the distance between two charges upon their attraction or repulsion?

10. If two small balls, 1 inch apart, each having a charge of 2 millionths of a coulomb, attract with a known force, how much harder will they pull if the charge on one is increased to 4 millionths of a coulomb? If both charges are increased to 4 millionths of a coulomb?

11. If the two balls of Question 10 are 2 inches apart, how much will their attraction be decreased? If 4 inches?

12. If two charged balls have their charges doubled, and are at the same time separated to twice the distance they were at first, will their force of attraction or repulsion be changed? Why not?

13. Would the attraction between two charged balls be the same through oil as it is through air?

14. What is a coulomb?

15. Why do two charges attract or repel each other in the proportion of the product of their charges?

16. What is an electrometer?

17. On what part of a conductor does electricity tend to stay?

18. If a deep pan is charged, where is the charge to be found?

19. Why will a charge tend to stay on the outside of a hollow cylinder?

20. How can an object be protected from electric induction?

21. What is an electric screen?

# CHAPTER III

## ELECTRICAL POTENTIAL, ELECTRICAL MACHINES, AND ELECTRICAL CAPACITY

**16. Difference of Level or Potential.** — Many of the simpler phenomena of electricity may be illustrated by the action of fluids, but the reader must carefully bear in mind that the comparison is merely for convenience, and that electricity is not a fluid, but is perhaps a form of strain, or the effect of a vibration, in the ether.[1] It must also be remembered, in using these comparisons, that we do not touch upon the true nature of electricity, which is not known, but *only upon the laws of its action which have been experimentally determined.* Also, that while water and gas may be directly perceived by our senses, electricity is absolutely impalpable, — that is, it cannot be directly perceived by our senses, — and the only way in which we may recognize it is by its various effects.

If we consider two vessels of water at different levels connected by a hose, it is evident at once from our ordinary experience that water will flow from the vessel of higher level to the vessel of lower level. In this case there is a tendency for the water to flow on account of the difference in level which causes a pressure, or motive force, which is measured by the **Difference of Level or Potential** between the water in the two vessels. If the vessels are placed at the same level, no water will flow. This analogy may be used to illustrate the flow of electricity between two charged conductors at the instant that they are connected together by a wire, under the conditions mentioned on page 6. One of the bodies is supposed to hold a positive charge and the other a negative charge, and the flow is considered to be from the positively charged body to the negatively charged body. Considering that the body with the positive charge is at a higher electrical level, or potential, than the body with the negative charge, we may say that the flow of electricity is caused by the difference of electrical level of the charges on the bodies, which results in an **Electrical Pressure** or **Electromotive Force.** No flow of electricity would occur if the bodies were at equal electrical levels at the time the wire connected them.

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[1] Article 2.

**17. Relative Potentials.**—The terms "positive charge" and "negative charge" are by this view shown to be terms to indicate that one body is at a higher potential than the other, that is, that electricity will flow from one to the other if they are put in contact; and we may therefore have

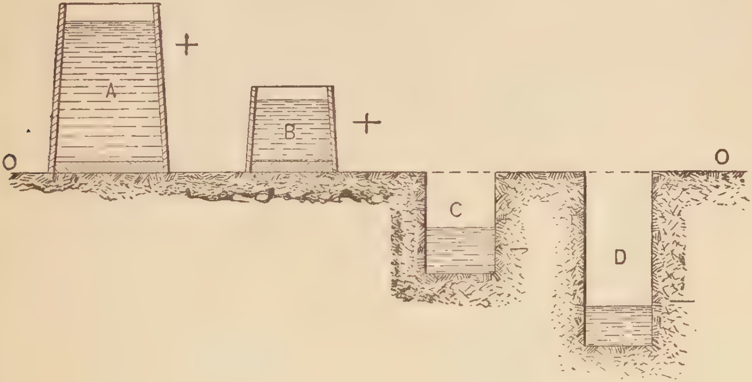

FIG. 5.—Illustration of Relative Potentials.

several charged bodies, one of which is negative to some and positive to others, just as amongst several vessels of water, one may be lower in level than some and higher in level than others.

The earth is usually considered to be at zero electric potential or level, though its potential varies with climatic and other conditions; exactly as the average height of the seas may be considered the zero level from which to measure the height of our water vessels.

An illustration of what is meant by the relative potentials of bodies may be had by reference to Figure 5. We will assume for convenience that the horizontal line marked *OO* is the zero level of the surface of the sea. Then the two tanks *A* and *B* will be at a positive potential, because they are at higher levels, while *C* and *D* will be negative, because they are below the zero level. The water in *B* may be considered to be negative with reference to the water in *A*, because it is of lower level, though, as we are referring them to the sea level as zero, it is less confusing to consider them both positive, but *A* of greater potential than *B*. The difference of potential between any two of the bodies of water will be directly proportional to their difference of levels, irrespective of whether they are positive or negative with reference to the sea level.

When we say that an electric charge is "positive," we usually mean that the charge is of a potential which is higher than that of our assumed zero, which is the earth; and when we say that an electric charge is "negative," we also usually mean that the charge is of a potential which is lower than that of our assumed zero. Such positive and negative charges are always on opposite sides, respectively, of the potential of the space with which they are surrounded, and they attract each other. Two positive charges (and likewise two negative charges), on the other hand, though they may differ from each other in relative potential, always repel each other because they are on the same side of the potential of the space with which they are surrounded.

All the space immediately around the earth partakes of its potential, except where the potential is disturbed by the influence of local charges. This space, which is affected with the earth's potential, is called the **Electric Field** of the earth, or the earth's **Electric Field of Force.**

**18. Friction Machines for generating Electricity.** — From the preceding articles it is evident that a simple machine may be made for the generation of electricity by an arrangement for continuously rubbing glass with silk or other similar material, with some device added for collecting the electricity which is developed. A German named Von Guericke first built such a machine in 1650. In this a large ball of sulphur was revolved. When any person pressed his dry hands upon the sulphur ball the friction generated electricity, and his body became charged. Later, a glass cylinder or plate and a rubber of silk or leather came into use.

In such machines, the charge upon the glass is usually collected by induction. A row of points, called a **Comb,** attached to an insulated brass block, is presented to the charged surface of the glass (Fig. 6). The positive charge on the glass causes the far side of the brass conductor to become positively charged, and the row of points to become negatively charged. The particles of air surrounding and in contact with the points become negatively charged, and are repelled off to the positively charged glass. This leaves the brass conductor with a positive charge, and the negative charge of the air particles neutralizes the positive charge of the glass, which is therefore ready to be again excited as it again moves around to the rubber. The action is continuous while the glass is revolved.

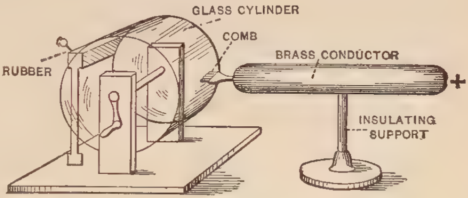

FIG. 6.—Glass Cylinder Electrical Machine.

By sprinkling the rubber with a conducting powder or an amalgam made with mercury, the negative charge of the rubber may also be drawn away. If the positively charged brass conductor is then connected by a wire to the rubber, a continuous flow of electricity will pass from the brass conductor to the rubber. If there is a small break in the wire the electricity will jump across it in the form of a spark.

The friction of a jet of wet steam passing through a wooden nozzle, and many other methods, may be used to generate electricity in a similar way by friction.

**19. Induction Machines; the Electrophorus.**—The quantity of electricity generated in a reasonable time by frictional methods is comparatively small, and machines operating by induction are more used. The simplest device of this kind is called an **Electrophorus.** This consists of a plate of sulphur, vulcanized rubber, or similar material, and a metal plate or cover with an insulating handle (Fig. 7). Rubbing the sulphur or rubber with flannel electrifies it negatively. When the cover is set down it touches the base at only a few points on account of its roughness, and it be-

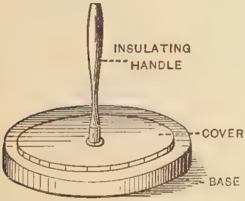

FIG. 7.—Electrophorus.

comes electrified by induction in the manner illustrated in Figure 8. The negative induced charge may be allowed to escape into the operator's body by touching the cover with a finger, as explained in Article 8. The cover then remains with a positive charge, which may be used to charge other bodies.

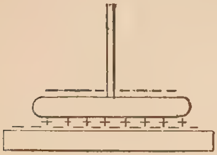

FIG. 8. — Illustration of the Induced Charges on the Cover of an Electrophorus.

The process of charging the cover may be repeated again and again without affecting the charge on the base, but the latter will be slowly dissipated through dampness in the air.

**20. The Holtz Induction Machine.** — What is known as a Holtz electric machine may be roughly described as an automatic electrophorus. This consists of two parallel plates of glass, one of which is mounted to rotate, with certain inducting and collecting devices (Fig. 9). The following is a brief explanation of the action of this machine: At opposite points on the stationary plate holes or windows are cut, and over these are pasted pieces of paper called Sectors. These are given opposite charges by means of rubbed rods of glass and sealing-wax, or by other means. In front of the revolving plate opposite each sector is a comb. The charges on the sectors act indirectly on the combs and the conductors attached to them, so that the knobs that terminate the conductors are charged with opposite kinds of electricity. The electricity which is attracted into the combs flows off on to the revolving plate exactly as was explained in the case of the cylinder friction machine, and charges it as shown in Figure 10. The charges on the revolving glass are carried around under the opposite combs, and act inductively on them, and are then neutralized by the charges

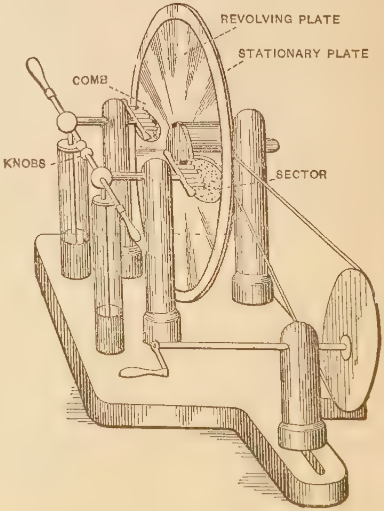

FIG. 9. — Holtz Machine.

on the streams of air particles passing off the combs. If the two knobs are placed in connection, a flow of electricity passes through the conductors out of the combs on to the revolving plate, which is thus kept charged, as in Figure 10, and the current of electricity continues as long as the plate is revolved. If the plate is revolved with sufficient rapidity a spark will jump from knob to knob, thus completing the circuit, even when the knobs are a considerable distance apart.

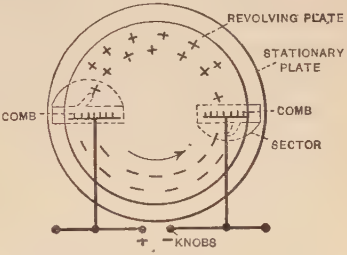

FIG. 10. — Illustration of the Operation of a Holtz Machine.

In starting the machine, it is really sufficient to charge only one of the sectors, as the other will then become charged through the action of the machine. It is not necessary to go fully into the action of these machines, or into that of various devices used to increase their effectiveness and make them self-exciting.

**21. Hydraulic Analogy.** — The action of Holtz and similar machines may be compared, in a rough but handy analogy, to pumps for circulating water or gas through a system of pipes. The machines may be considered to be machines for pumping electricity.

Suppose two deep tubs to be placed side by side, and a pump to be connected in a pipe leading from the bottom of one to the bottom of the other. If the tubs are partly full of water and the pump is started, water will be drawn from one tank and sent into the other one, thus raising the water level in the latter. If an overflow pipe is carried from the upper tub to the lower one, the overflow will run back into the lower tank, and the water will be simply circulated by the pump through the system of pipes between the two tanks.

This is similar to the conditions of an electrical machine when the positive and negative terminals are connected together or sparks are passing between them.

Now, if the overflow pipe is stopped up, and drip pans are arranged so that water from the upper tank cannot run down into the lower one, the pump will soon empty the lower tank, after which it may continue to run, but it cannot pump any water, and no stream will flow through the pipes.

In the same way, if the two conductors of an electric machine are not connected, and are too far apart for a spark to pass between them, the conductors will be strongly charged with opposite kinds of electricity (that is, their difference of electrical level or potential becomes great), but then the action of the machine in circulating electricity must cease until a path is provided for the current to flow.

**22. The Ampere.** — The quantity of water circulated by the pump depends upon the pressure which it produces, and upon the size of the connecting pipes; and a similar rule holds for the circulation of electricity by an electrical machine. The volume of the stream of water may be designated as a certain number of gallons or cubic feet per second. In the same way the volume of a current of electricity may be designated as one which conveys a certain number of coulombs per second. An electric current carrying one coulomb per second is called a current of one **Ampere**, and the volume of an electric current is always given in amperes. This name was given in honor of a great French scientist whose name was Ampère.

**23. The Volt.** — To pass a stream of a certain number of gallons per minute through a certain pipe demands the application of a certain pressure to overcome the frictional resistance. In the same way it requires a certain **Electrical Pressure**, or difference of potential, to pass a given electrical current through any conducting wire, on account of the resistance which the wire offers to the flow of the electricity. The resistance to the passage of electricity, or the **Electrical Resistance**, in any material, is the reciprocal or opposite of its conducting power. *The greater its conducting power, the less is its electrical resistance.*

We usually measure water pressure, or the pressure of gas, in pounds per square inch, or in feet difference of level, or head. The corresponding unit of electrical pressure is a **Volt**, which was named after Volta, a great Italian scientist.

Returning again to the pump and tanks, — when the pump is set in motion, it sets up a difference of pressure which may be measured by a gauge, and this starts the water to flowing if it has an outlet. In the same way we may look upon electrical machines as setting up a difference of electrical pressure (which may be measured by a proper electrical instrument), and this starts the electricity to flowing if it has an outlet.

This leads us to the necessity of considering a positive charge of electricity as electricity at high electrical pressure or high potential, and a negative charge as electricity at low electrical pressure or low potential.[1]

When a point of high electrical pressure is connected by a conducting wire to a point of lower pressure, electricity will flow from the higher point to the lower, until the pressure is equalized, unless the difference of pressure is continually kept up by a machine; exactly as has been explained, where two tanks, standing side by side, are filled with water to different heights, and are connected by a pipe, — in which case water will flow from one to the other until the level is the same in both.[2]

**24. Pressure produced by Electrical Machines.** — Before leaving the question of electrical machines working by friction and induction, it is well to call attention to the great pressure of the electricity generated by them. This is shown by the sparks which may be caused by them to pass through the air, or even to pierce wood, glass, or other solid insulators. These effects may be called miniature lightning effects, for lightning is simply caused by the passage through the air of a current of electricity under enormous pressure. Thunder is like the crackle of the spark from an electrical machine greatly magnified.

While the electrical pressure generated by these machines is very great, the quantity of electricity generated is quite small, and for commercial purposes, in which a considerable volume of electricity is needed, other methods of generating the current are used. These are described in later chapters.

**25. Lightning.** — The identity of electrical discharges and lightning was demonstrated at the instance of Benjamin Franklin (one of the boldest experimenters and most brilliant thinkers the world has ever produced). He himself secured unimpeachable evidence of this identity in 1752, by his classical experiment of drawing an electrical discharge from a thunder cloud along the string of a kite. It was through Franklin's suggestion that lightning rods came to be erected, and by 1782 at least four hundred were in use in Philadelphia. It has never yet been conclusively determined how the clouds get their great charges of electricity which produce the lightning strokes.

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[1] Articles 16 and 17.

[2] Article 16.

**26. Electrical Capacity.** — If the bottom of one of the tanks described in the first articles of the chapter, which is filled with water, is connected by means of a pipe to the bottom of its mate of different diameter, which stands on the same level, the water will flow into the second tank until it stands at the same height in both. The quantity of water in each vessel, when the flow has ceased, *is proportional to the capacity of the vessel.* During the flow, the water falls in one vessel and rises in the other. In the same way if a conductor, such as a brass ball carrying an electric charge, is touched by an uncharged conductor, part of the charge flows to the second conductor. During the flow the electric pressure of one conductor falls and the pressure of the other rises. After the flow has ceased, the electrical pressures of the two conductors are equal. The quantities of electricity on the two conductors are not equal unless the conductors are exactly similar, but the quantity on each will depend upon its capacity to hold electricity, or its **Electrical Capacity**. The electrical capacity of a conductor depends upon its size, shape, and surroundings. It is measured by the *number of coulombs of electricity required to raise the electrical pressure of the conductor one volt*, exactly as the capacity of a cylindrical tank is measured by the number of gallons of water required to fill it to the depth, or head, of one foot.

The electrical pressure of a conductor carrying a charge of electricity is ordinarily reckoned as the difference between it and the average electrical pressure of the earth's surface, which is called zero. This is similar to the reference of levels or heights to the sea level as a zero point from which to start.

**27. The Farad.** — When the pressure of a conductor is raised one volt by the charge of one coulomb, the conductor is said to have a capacity of one **Farad**, after Faraday, the distinguished English scientist.

**28. Condensers.** — The presence of charges of an opposite sign near a charged conductor has a remarkable influence on the conductor's capacity. For instance, if pieces of tinfoil are pasted upon the two sides of a sheet of mica, and the two tinfoil coatings are given opposite charges, the charges act inductively on each other and increase the capacities of the coatings by modifying their relative potentials. Such an arrangement is called a **Condenser.** The tinfoil sheets are called the **Coatings** or **Plates** of the condenser, and the insulating material is called the **Dielectric**. The coatings of a condenser may be made of any conducting material, and the dielectric of any insulating material.

The combined capacity of the coatings is the capacity of the condenser. *A condenser has a capacity of one farad when the transfer of one coulomb of electricity from one plate to the other changes the difference of electrical pressure, or potential, between the plates by one volt; and the quantity of electricity in a charged condenser is equal to the product of the capacity of the condenser* (*in farads*) *with the difference of pressure between the plates* (*in volts*). This may be represented algebraically by the expressions

$$Q = SV, \text{ and hence } S = Q/V \text{ and } V = Q/S,$$

if $Q$ is taken to represent coulombs, $S$ to represent farads, and $V$ to represent volts. To "charge a condenser with a certain quantity of electricity" means that a positive charge of the given quantity is placed upon one plate and an equal negative charge on the other plate.

A farad is a much larger capacity than is ordinarily found in electrical work, so that capacity is usually reckoned in millionths of a farad, or **Microfarads** (from micro, meaning little).

*Example.*—What pressure is required to charge a condenser of 10 microfarads capacity with .03 coulombs of electricity. *Ans.* 3000 volts.

A condenser may be charged in either of two ways:—

First, by connecting one plate to earth and placing the charge on the other plate, when the required opposite charge will collect on the grounded plate by induction.

Second, by connecting the two plates of the condenser to the two terminals of an electrical machine, or other source of electricity, when the charge is communicated by the machine, which acts as an electricity pump.

Every electrical conductor, as we have seen, has capacity, and when an insulated wire is laid in the earth or is strung overhead it becomes one plate of a condenser. The other plate of the condenser is the earth, and the dielectric is the insulating covering of the wire, or the air which is between it and the earth. The capacity of a wire has a great deal of effect on its usefulness in telephone service. Every hundredth of a microfarad per mile of conductor reduces very considerably the distance through which the telephone will work satisfactorily. The capacity of ocean cables is also a matter of much importance, and capacity effects are of importance in telegraphy and in the transmission of power by alternating currents of electricity.

**29. The Leyden Jar.** — For experimental purposes a condenser is sometimes made by coating the inside and outside of a glass jar with tinfoil. Such an arrangement is called a **Leyden Jar.** In this case the inside and outside coatings, respectively, are the condenser plates, and the intervening glass of the jar the dielectric. A group of nine Leyden jars in a box is illustrated in Figure 11.

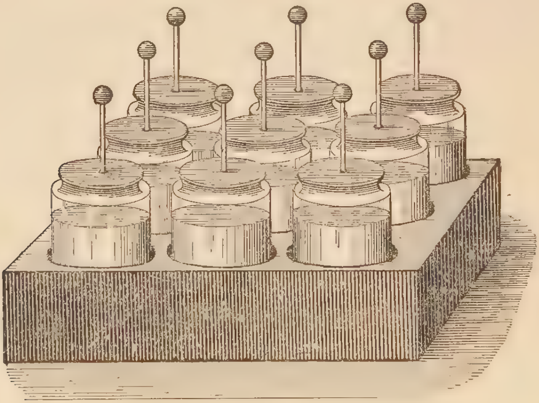

FIG. 11. — Battery of Leyden Jars.

## QUESTIONS

1. Explain the meaning of the phrase difference of potential.
2. Compare difference of electric potential with difference of water levels.
3. What is the assumed zero of electrical potential ?
4. Can a charge be negative with reference to another and still be at a higher potential than the earth ?
5. What potentials are usually considered to be positive and what negative? What is used as a standard to determine this ?
6. What is a friction electrical machine?
7. How can you make a friction machine for generating electricity?

8. What is an induction electrical machine?

9. What is an electrophorus?

10. How is an electrophorus used?

11. When an electrophorus cover is set upon the charged plate, why does it not rob the plate of its charge?

12. If the plate of an electrophorus is charged positively and the cover placed upon it, why will the cover retain a negative charge if it is touched by the finger before it is removed?

13. Describe a Holtz machine.

14. What are the sectors in a Holtz machine for?

15. Explain the complete action in a Holtz machine.

16. Compare the action of electrical machines with a pump.

17. What is an ampere?

18. If 10 coulombs of electricity flow through a conductor in a second, how many amperes compose the current?

19. If 50 coulombs of electricity flow through a conductor in 10 seconds, how strong is the current?

20. If a current of 10 amperes is carried by a conductor for 10 seconds, how many coulombs of electricity pass through the conductor?

21. What is a volt?

22. What is it that is measured or expressed in volts?

23. What is meant by the resistance of a conductor?

24. What relation has resistance to conductivity?

25. Why are friction or induction electrical machines of small commercial value?

26. What is electrical capacity?

27. Compare the capacity of a conductor for holding electricity with that of a cylindrical tank for holding water.

28. What is a farad?

29. After whom was this unit of capacity named?

30. What is a condenser?

31. What is a dielectric?

32. Why is the combined capacity of two plates increased when they are brought close together?

33. How may a condenser be charged?

34. Do all conductors have capacity?

35. When has a condenser a capacity of 1 farad?

36. What capacity has a condenser if a charge of 20 coulombs raises the pressure between its terminals by one volt?

37. Would the condenser of the preceding question be very large or small compared with those likely to be met with in electrical work?

38. Describe a Leyden jar.

# CHAPTER IV

## ELECTRIC BATTERIES, OR APPLIANCES FOR TRANSFORMING CHEMICAL ENERGY INTO ELECTRICAL ENERGY

**30. Electric Batteries.** — One of the effects of chemical action is to give out heat. When wood or coal is burned, the carbon of the burning material combines with oxygen from the air, and heat is given out as the result of the chemical combination which we call **Combustion** or burning. In the same way, if zinc is dissolved in sulphuric acid, the acid combines with the zinc, and heat is given off as the result of the chemical combination. This heat represents a certain energy or capacity for doing work. It has been found that under certain conditions *the energy thus represented by chemical action may be converted into an electric current*, and, taking advantage of this, we get **Electric Batteries.**

Electric currents produced by chemical action were first observed and studied about the end of the eighteenth century by Galvani and Volta, both of whom were Italian scientists. Volta will be recognized as the man from whose name comes the word "volt," the name of the unit of electrical pressure.[1]

**31. Two Different Metals dipped in a Liquid.** — When two plates of different metals are placed in a liquid so that they do not touch each other, as is shown in Figure 12, and the liquid is one which is inclined to attack them chemically, one of the plates becomes positively charged, and the other negatively charged, with electricity. The charges are so minute that they cannot be distinguished by the electroscope previously explained, but a delicate electrometer will distinguish and measure them.

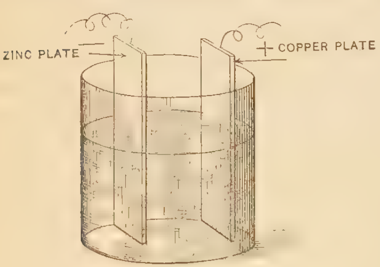

FIG. 12. — Simple Battery Cell.

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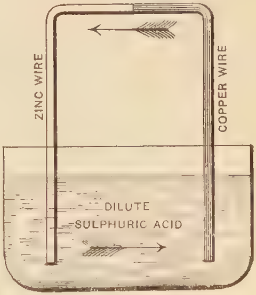
[1] Article 23.

If the metal plates are connected by a wire, a current flows through it from one plate to the other, and this may be readily distinguished by its effects, which are described in later chapters. The positive or high pressure plate is the one which is attacked least readily by the liquid.

**32. Voltaic Cell.** — It is almost exactly a century since Volta discovered that an electromotive force may be set up through actions, as above explained, in a more convenient manner than by charging two bodies with unlike charges. His discovery is at the foundation of a great deal of our electrical work of to-day, and in simple words may be explained as follows: When a complete conducting path or ring is made up of metal strips or wires, there is no electric action (provided all parts of the path are at the same temperature, and in like conditions in other respects), no matter how many different pieces of metal of various kinds are introduced into the ring.

Now, if an opening is made in the metal ring where two different metals join, and the two ends are dipped into a little acid, or a solution of salt, or some other chemically active liquid, a difference of potential is at once set up and an electric current flows around the ring. Particular attention should be given to the fact that the two ends of the ring dipped into the fluid must be composed of different metals in order that a current may flow. It therefore requires that at least three different conductors (in our illustration, two different metals and a liquid) shall be joined in a ring if a current flow is to be obtained; and at least one of the conductors, as for instance the liquid, must be of a different chemical class from the others.



ARROWS SHOW DIRECTION OF FLOW OF CURRENT

FIG. 13. — Illustration of Simple Voltaic Cell.

The arrangement under consideration is illustrated in Figure 13, which shows a ring composed of joined wires of zinc and copper, with their free ends dipping into a tumbler holding dilute sulphuric acid. The arrows show the direction of the flow of current. If we sever the wires outside of the liquid the electromotive force will still remain, but no current can then flow because the conducting path is broken. Upon again joining the wires, the current again can and does flow. Such an arrangement is generally called a **Voltaic Cell**, after the name of Volta.

In order to utilize the difference of potential, which we have been discussing, Volta first constructed what has since been called Volta's Pile. It consists of a pile of disks of zinc, cloth, and copper stacked up on each other in the order given until a stack as high as may be desired is obtained. The cloth is moistened with acid or a salt solution. Figure 14 illustrates the pile. If the upper copper is connected with the lower zinc plate by means of a wire, a current flows through the connecting wire. When there are enough sets of plates, the pressure and current set up will be sufficient to cause quite a spark, if the connecting wire is suddenly broken. Each of the sets of copper and zinc disks with acid or salt moistened cloth between composes a voltaic cell, and their differences of potentials all added together give quite a pressure. In this case, as before, the combination of materials, copper, zinc, and moisture, combine to give the pressure, while chemical action furnishes the necessary energy.

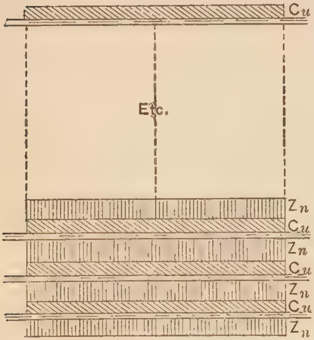


FIG. 14. — Volta's Pile.

Zn and Cu represent the zinc and copper plates, and the intervening material is the moistened cloth.

Volta also found that he could produce the electrical action by placing the zinc and copper plates in vessels containing dilute acid, the liquid taking the place of the moistened cloth, as in Figures 12 and 13. This arrangement forms the basis of our electric batteries of to-day.

**33. Unit of Electromotive Force or Pressure.** — When speaking of the tendency of electricity to move from one body to another, it is satisfactory to use the term "electrical pressure" instead of the longer term "electromotive force." In dealing with the flow of electricity, some unit for measuring this pressure must be adopted, just as in measuring differences of level we use the foot length as a unit and in measuring the tendency of water to flow we use the pressure of a pound per square inch as the unit. The unit of electrical pressure is called a volt,[1] after the name of Volta, and one volt of electrical pressure is a little more than the electromotive force of a Voltaic cell with zinc and copper plates and dilute sulphuric acid for the liquid.

**34. Energy expended in Continuous Flow.** — When two insulated conductors at different electrical pressures are connected by a wire, a brief current flows; just as a current of water flows through the pipe connecting two tanks in which water stands at different levels; but the current ceases as soon as the pressure is equalized. *In order that a continuous current may be produced, a difference of electrical pressure must be continuously supplied in a closed circuit.* If some method is introduced for maintaining the difference of potential or pressure (as would be the case, in our analogy of vessels of water connected by a pipe or hose, if we kept pumping the water from the lower to the higher vessel), the flow of electricity will be constant. One method of accomplishing this is by means of the electric batteries which have grown out of Volta's discovery, and which may be considered for convenience as chemical engines for pumping electricity from a lower potential to a higher.

If we desire to have a continuous flow of water from one vessel to another one at lower level, it is necessary to keep refilling the higher vessel as water runs out of it. To do this, the water must be raised from the lower level to the higher, which means that work must be performed and energy expended. There are various ways in which this energy may be supplied: we may carry the water up in hand buckets, thus using up animal energy; we may divert rain water or a flowing stream into the higher vessel, thus utilizing the effects of the energy from the heat of the sun, by means of which the water was raised from the earth to become clouds; we may pump the water directly from the lower vessel to the upper one by means of a pump driven by a steam engine, thus utilizing the energy of the steam, which was given to it from the heat of the burning coal.

We may then say that it requires a continuous expenditure of energy to keep water continuously in circulation. Some of this energy may be recovered by putting water motors in the hose or pipe through which the water flows from the higher to the lower vessel, but much of the energy is lost by friction in the pipes and pump.

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[1] Article 23.

In the same way, it requires a continuous expenditure of energy to keep an electric current flowing, and this energy may be gained from the chemical energy resulting from dissolving zinc or some other metal in an electric battery.

**35. The Battery Cell and Electromotive Force.** — A cup containing two plates immersed in a liquid such as has been described, is also called an **Electric Battery Cell**, and the plates are called the **Poles or Electrodes** of the cell. It is usual to speak of the electrode which is at the higher pressure, and from which current flows through an external wire, as the **Positive Pole** or **Positive Plate**; the other electrode is called the **Negative Pole** or **Plate.** The liquid is called the **Electrolyte.** The difference of electrical pressure between the poles is called the electromotive force of the cell. The phrase "electromotive force" means a force which tends to move electricity, that is, a difference of electrical pressure or potential. This phrase is often abbreviated into E.M.F. We will generally speak of it, however, as the electrical pressure of the cell.

An electric battery is often called a **Voltaic** or **Galvanic Battery**, and the electricity produced by a battery is often called **Voltaic** or **Galvanic Electricity**, although the electricity is exactly the same as that produced by any other means. These terms are applied in the same way as the terms "Spring Water" and "Well Water," for instance, are applied to pure water which is drawn from a spring or well, though the water does not differ from pure water drawn from other sources.

**36. Complete Circuit of Electric Flow.** — When the poles of a cell are connected by a wire it is found that an electric current not only *flows from the positive to the negative pole through the wire*, but it *continues through the liquid from the negative to the positive pole.* If the current is followed from any point in its flow, it will be found to return through a complete path to the same point, exactly as water is circulated by a pump through a system of pipes. A continuous current of electricity is therefore said to flow in a **Complete Path** or **Circuit.** A complete circuit is often called a **Closed Circuit.**

*The current inside the cell, then, is driven by the effect of chemical action against a difference of pressure*, just as water may be raised by a pump against a difference of pressure. *Outside of the cell*, where there is no restraining action besides that of the electrical resistance of the connecting wire, *the current follows its own tendency to flow from the point of high pressure to that of low pressure.*

**37. Electrical Pressure of Cells.** — The magnitude and direction of the electrical pressure between the poles of a battery cell depend upon the materials in the plates and the character of the liquid. For instance, if zinc and copper compose the plates of a cell containing sulphuric acid, the electrical pressure of the cell is about nine-tenths of a volt and the copper plate is the positive pole. If two cells are made with sulphuric acid as a liquid, using zinc and lead for the plates of one cell, and lead and copper for the plates of the other, the lead is the positive plate in the former and the negative plate in the latter. Also, the electrical pressure developed in each of these is less than in the case of the zinc-copper cell.

In cells which are to be obtained from dealers, the negative poles or plates are nearly always of zinc, but the metals composing the positive plates and the compositions of the liquids vary greatly. The positive plates are generally made of copper, carbon, or platinum, and the liquids consist of various acids, or solutions of sal ammoniac, caustic potash or other compounds in water.

**38. Connection in Series.** — If a number of cells, such as the zinc-copper cell described above, are connected in a series with the zinc pole of one connected to the copper pole of the next, and so on, as is illustrated in Figure 15, then the total electrical pressure measured between the free copper pole and the free zinc pole is equal to the *sum of the pressures developed by all of the individual cells.* When a battery is connected in this manner so that the pressures developed in the individual cells are all added together, the cells are said to be **Connected in Series.**

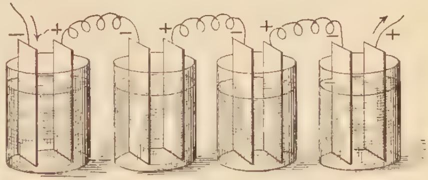

FIG. 15. — Four Voltaic Cells Connected in Series.
Terminals of copper plates are marked +.
Terminals of zinc plates are marked −.

**39. The Pressure of a Cell is Independent of its Size.** — The electrical pressure of a cell depends only upon the nature of the plates and the liquid, and *is entirely independent of the size of the plates.* This can be easily proved by making two cells out of tumblers containing dilute sulphuric acid, in one of which are placed narrow strips of copper and zinc, and in the other are placed broad strips of the metals. If these are connected in series and the circuit is closed by joining the free poles by a wire, a current flows, as is shown by the vigorous chemical action which causes bubbles to gather on the copper plates. If one of the cells is now reversed, so that its copper pole is connected to the copper pole of the other, no such action occurs, which shows that the electrical pressures which now tend to send currents in opposite directions are equal and neutralize each other.

**40. Polarization.** — If the two poles of a zinc-copper cell, such as we have been considering, are connected by a wire, a vigorous chemical action goes on at first, but it gradually decreases in intensity and finally appears to stop altogether. This effect may be plainly shown by connecting an electric bell in the circuit of the cell. When the circuit is first completed the bell rings loudly, but it soon weakens, and after a time ceases to ring altogether. If the cell is then examined, a layer of bubbles may be found upon the copper plate. These bubbles are composed of hydrogen gas which is liberated from the sulphuric acid by the chemical action in the cell. The effect of the hydrogen bubbles is twofold: first, the hydrogen in contact with the electrolyte in the cell tends to produce a smaller electric pressure than is set up between the copper and the electrolyte, and thus the effective pressure of the cell is reduced; second, the layer of bubbles presents a high resistance to the flow of the current.

A cell which is made inactive by a layer of hydrogen bubbles, is said to be **Polarized**, and the effect is called **Polarization**.

**41. Depolarization.** — In order that a cell may be capable of working continuously, some plan must be adopted to keep it from polarizing, or, as it is often called, to keep it **Depolarized**. This may be effected in three different ways: first, by mechanical action; second, by direct chemical action which absorbs the hydrogen; third, by electrochemical action, by which the hydrogen is exchanged for a metal which is deposited upon the positive plate.

**42. Open and Closed Circuit Cells.** — In all cells that use a mechanical method of depolarization and in many that use a chemical depolarizer, the depolarizing is effected so slowly that the cells cannot give a long continued steady flow of current, and for that reason they are called **Open Circuit Cells.** These cells are extensively used for ringing bells, for setting signals, for telephones, etc., where the work is intermittent and the cells have time to regain a proper working condition while resting between the periods of activity.

A majority of the cells making use of the electrochemical methods of depolarizing, have no tendency to polarize, and may therefore be used continuously. Such cells are called **Constant or Closed Circuit Cells.**

## QUESTIONS

1. What are electric batteries?
2. How is the energy for an electric current obtained in an electric battery?
3. What happens when two dissimilar plates are dipped into an electrolyte?
4. If the plates are connected by a wire, which one is attacked by the electrolyte?
5. After whom was the volt named?
6. What did Volta discover?
7. Describe a voltaic cell.
8. Describe a voltaic pile.
9. Must energy be continually expended to keep a current flowing through a battery circuit?
10. Which is the positive pole of a cell?
11. What are the electrodes of a cell?
12. What is the electrolyte of a cell?
13. Is there any difference between electricity generated by a battery and that generated by other means?
14. What is a closed circuit?
15. Will electricity flow if the circuit is open?
16. Is the pressure in all kinds of battery cells the same?
17. Which pole is positive in a zinc-copper-sulphuric acid cell?
18. In two cells, both using sulphuric acid, but one having zinc and lead electrodes and the other lead and copper, in which is the lead positive? In which is it negative?
19. What are some of the materials used in making batteries?
20. How are cells connected in series?
21. If 10 cells, each of which produces a pressure of 2 volts, are connected in series, what will be the total pressure?
22. Does the size of the cell electrodes affect the pressure produced?
23. How can it be shown that the size of the electrodes does not affect the pressure?
24. What causes the ordinary polarization which occurs in primary cells?

25. What are the effects of the hydrogen bubbles that collect upon the copper plates in a zinc-copper-sulphuric acid cell?

26. Why is the pressure which the hydrogen tends to set up called a *counter* electric pressure?

27. In what three ways may depolarization be effected?

28. What are open circuit cells?

29. Why can open circuit cells be used satisfactorily for ringing electric door bells?

**43. Mechanical Depolarization.**—The first method of depolarizing requires that the hydrogen bubbles be cleared off the positive plate as fast as they are deposited upon it. This may be done by continuously stirring the liquid or blowing air into it. If the positive plate is well roughened, the hydrogen bubbles will not stick to it so closely, but many will float off to the surface of the liquid and escape. This plan was employed in a cell commonly called Smee's cell, which was used commercially many years ago, but it was not very successful.

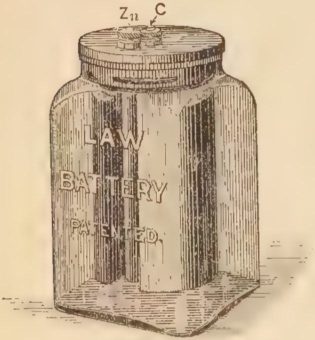

FIG. 16.—Open Circuit Cell with Positive Pole composed of a Slit Hollow Cylinder of Carbon which nearly surrounds the Negative Pole made of Zinc Rod.

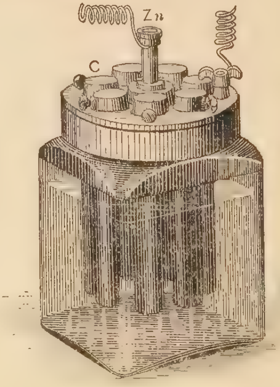

FIG. 17.—Open Circuit Cell with Positive Pole composed of a number of Carbon Rods set in a Circle around the Negative Pole made of Zinc Rod.

There are also a great many cells used for ringing bells, etc., that depend entirely upon the use of a large positive plate surface to lessen the rapidity of polarization. It is evident that such cells can only be used intermittently. Figures 16 and 17 show two forms of these cells.

They consist almost always of zinc and carbon electrodes immersed in a solution of sal ammoniac (the scientific name for which is ammonium chloride). The carbons are made with very large surfaces and in endless variety of forms.

**44. Chemical Depolarization; Bichromate Cells.** — If some substance is added to the liquid of the cell which will combine with the hydrogen as quickly as it is formed, the polarization will evidently be avoided. This is the foundation of the second method of depolarizing. Various substances may be used for this purpose, but dioxide of manganese, bichromate of potash, bichromate of soda, chloride of lime bleaching powder, and nitric acid are used most commonly. The well-known **Bichromate Battery**, which is often used to run small motors, ignite the gas in gas-engines, and for similar purposes, is a zinc-carbon battery, with a liquid composed of sulphuric acid in which bichromate of potash or soda is dissolved. When this cell is in operation, polarization is prevented by the immediate combination, with the bichromate of potash or soda, of the hydrogen which is liberated from the sulphuric acid. Carbon is used for the positive plate in this cell because the bichromate of potash will attack and destroy copper. In the bichromate battery the zincs are generally arranged so that they may be lifted out of the fluid when the cells are not in use, because the fluid eats up zinc when the circuit of the cell is open. From this comes the name **Plunge Battery** (Fig. 18).

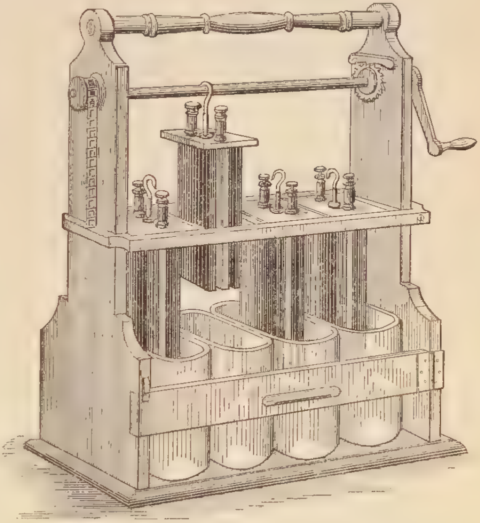

FIG. 18. — Bichromate Plunge Battery.

The ordinary proportions in which the solution for this type of battery is made up are as follows, the parts being measured by weight: —

180 parts of water.
25 parts of commercial sulphuric acid.
12 parts of bichromate of potash, or bichromate of soda.

The crushed bichromate should first be dissolved in the water at boiling temperature, after which the acid may be added to the cooled solution.

There are a large number of cells using the bichromate, or chromic acid, as depolarizers, for a description of which reference should be made to a book specially describing primary batteries.

**45. Chemical Depolarization; Bunsen and Grove Cells.** — When nitric acid is used as a depolarizer, it cannot be allowed to come in contact with the zinc, which it attacks vigorously; consequently it is confined in a porous earthenware cup within which is the positive pole of carbon or platinum. Figure 19 shows such a cell complete, and Figure 20 shows the same cell in cross section. The earthenware porous cup is sufficient to prevent the liquids from mixing, but after it has become well soaked it does not present much resistance to the passage of an electric current. The cells which are made up with nitric acid for the depolarizer are only useful for furnishing current for experimental purposes, and

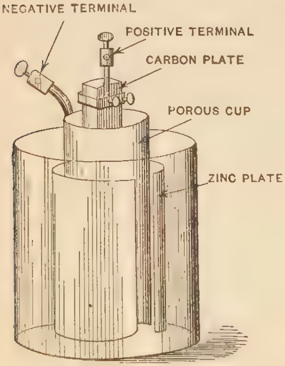

FIG. 19. — Bunsen Cell.

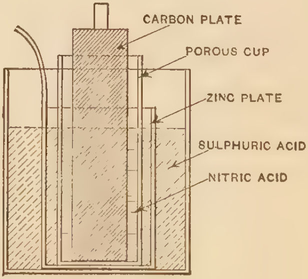

FIG. 20. — Sectional View of Bunsen Cell.

for that purpose they are much more expensive than dynamos. They have, therefore, practically gone out of use. The commonest forms of cells of this type are known as **Bunsen's** and **Grove's Cells**. The action of the nitric acid as a depolarizer is quite similar to that of bichromate of potash, but it is more powerful.

**46. Chemical Depolarization; Copper Oxide and Silver Chloride Batteries.** — Copper oxide as a depolarizer was made use of originally by Lalande and Chaperone. In America, probably the best-known type of cell using copper oxide is that called the Edison-Lalande cell. Figure 21 exhibits this cell, in which *Z* represents the zinc electrode, and *C* the positive or copper electrode which consists of a plate of compressed copper oxide. The liquid used is caustic potash or soda dissolved in water. A layer of paraffine oil is placed over this liquid to prevent action upon it by the carbonic acid of the air, which would not only destroy its effectiveness, but also by a secondary reaction

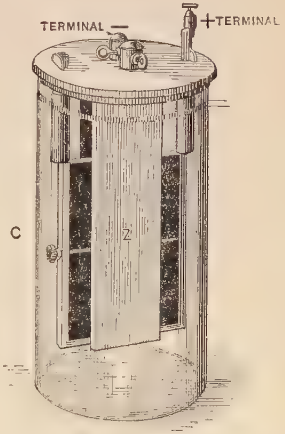

FIG. 21. — Cell with Copper Oxide Depolarizer.

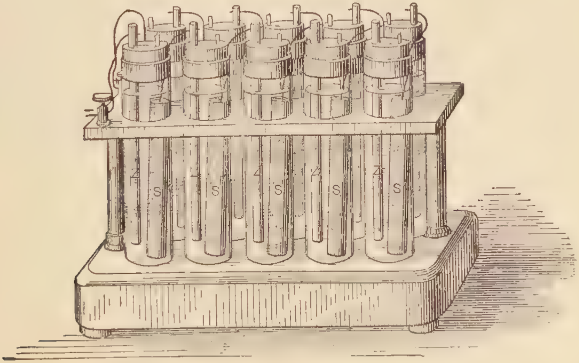

FIG. 22. — Silver Chloride Battery.

would destroy the copper oxide. The hydrogen set free when the cell is in action combines with the oxygen of the copper oxide plate, thus preventing polarization. This cell is used extensively for medical purposes.

A chloride of silver battery is shown in Figure 22, where *Z*, *Z* are the zincs, and *S*, *S* are the silver plates upon which silver chloride has been cast. The liquid used is ammonium chloride, or sal ammoniac. Zinc chloride is formed at the zinc plates, and the free combination of hydrogen and nitrogen which results from the action of the battery forms ammonium chloride at the silver plates by drawing chlorine from the silver chloride depolarizer. The silver chloride battery is especially adapted for electric testing, and should not be required to furnish large currents.

**47. Chemical Depolarization; Leclanché Cells.** — When dioxide of manganese is used as a depolarizer, it is generally broken up into small lumps and put into a porous cup surrounding a positive plate of carbon.

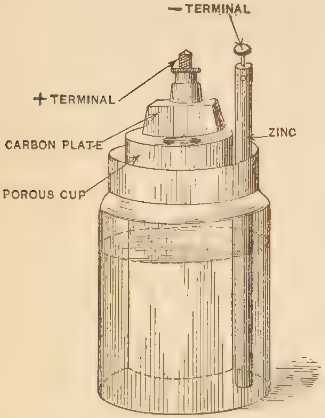

FIG. 23. — Leclanché Cell with Porous Cup.

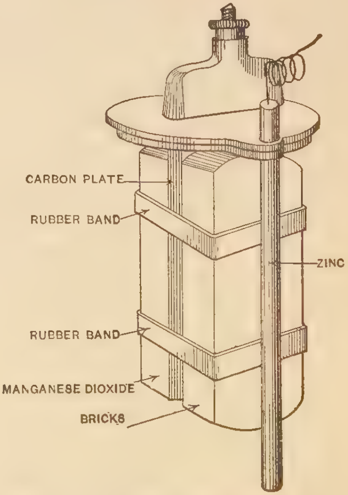

FIG. 24. — Carbon Plate with Dioxide Prisms, Zinc, and Cover of "Prism" Leclanché Cell.

When sal ammoniac dissolved in water is used as the liquid in this form of cell, it makes the familiar Leclanché battery (Fig. 23), which is used so frequently in ringing door bells and in doing similar service. Sometimes the dioxide of manganese is pulverized and mixed with shellac, after which it is pressed into small bricks, which are placed upon either side of the carbon positive plate (Fig. 24), as in the "prism" Leclanché battery. The depolarizing effect of dioxide of manganese is not sufficiently powerful to prevent a cell from becoming polarized if used constantly. Consequently, Leclanché cells are only satisfactory in service which is intermittent, like ringing door bells, where the circuit is open a considerable part of the time and the battery rests without chemical action. Leclanché cells are called open circuit cells on account of the small chemical action which goes on in them when the circuit is open, and because they are not satisfactory in continuous service.[1]

**48. Electrochemical Depolarization; Daniell's Battery.** — The third method of depolarizing introduces more complicated chemical reactions, but of these we need not give much detail. Through the use of this method cells are constructed which give excellent results in continuous service, and which are, therefore, called closed circuit cells.[2] One of these is probably the most commonly used of any form of battery. This is the ordinary **Gravity Battery**, or copper sulphate battery, which is so much used in telegraphy.

In the original Daniell's cell from which the gravity cell came, the active liquid is dilute sulpnuric acid in which is immersed the zinc or negative plate. The copper plate is immersed in a depolarizing solution of ordinary copper sulphate, or blue vitriol (sometimes called bluestone). The two solutions are separated by a porous cup. In general terms the chemical action which occurs when the battery is working is as follows: The sulphuric acid attacks the zinc, and sulphate of zinc is formed. At the same time hydrogen is liberated from the sulphuric acid and goes toward the copper plate, where it would be deposited if it were not for the copper sulphate which surrounds the copper plate. When the hydrogen gets into the copper sulphate solution, it goes into combination, and copper is separated from the solution and deposited upon the copper plate, which is therefore kept bright and in good working condition.

During the operation of the cell the chemical action which has been briefly explained causes a change in the character of the solutions. The sulphuric acid changes to a solution of sulphate of zinc, and the copper sulphate changes to sulphuric acid. If the sulphuric acid is replaced by a dilute or weak solution of zinc sulphate, a current is set up, as before, and the chemical action is similar, but the copper sulphate is converted into zinc sulphate. In order that the depolarizing action may continue during the **Life** of the cell, the strength of the copper sulphate solution must be kept up. This is done by putting crystals of copper sulphate or blue vitriol into the cell so that they may be dissolved. Figure 25 shows a cell of this battery in its original form, in which it is called Daniell's battery. In the figure, the zinc plate is shown within the porous cup at the right hand of the battery jar, and the copper plate is at the left hand of the jar. Alongside of the copper plate is a perforated copper cage in which may be put the copper sulphate for renewing the solution.

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[1] See, also, Article 42.

[2] See, also, Article 42.

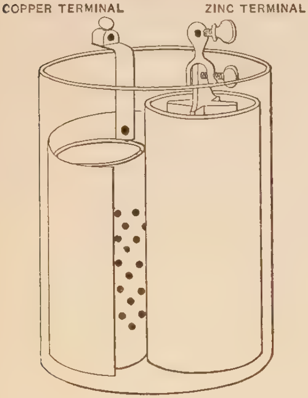

FIG. 25.— Daniell's Cell.

**49. Electrochemical Depolarization ; Gravity Cell.** — The sulphuric acid or zinc sulphate solution of this modification of the Daniell's cell is ordinarily much **Diluted** or weakened by water, while the copper sulphate solution is kept quite strong or **Saturated**. When in this condition the solution of zinc sulphate is lighter than the other, and will float upon it, just as oil floats on water. Consequently, if the copper plate, surrounded by the solution of copper sulphate, is placed in the bottom of a battery jar, a weak solution of zinc sulphate or sulphuric acid may be carefully poured on top, and the solutions will mix only very slowly. The zinc may be hung from the top of the jar in the upper solution (Fig. 26). This constitutes the gravity battery, so called because the solutions are separated by

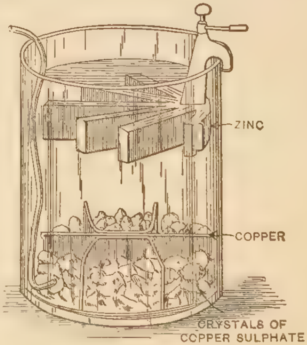

FIG. 26. — Gravity Cell.

gravity through the difference in their densities, instead of by a porous cup.

In setting up such a cell it is usual to put the copper in the bottom of the jar surrounded by crystals of copper sulphate. The jar is then filled with water to near its top, and the zinc is immersed in the upper part of the liquid. The cell may be placed on **Short Circuit** for a time, and it will work itself into good operating condition, or a little sulphuric acid or zinc sulphate solution may be carefully poured into the water, and the cell will at once be in condition.

If a gravity cell is allowed to stand upon open circuit, the two solutions will slowly mix by **Diffusion.** When any of the copper sulphate solution reaches the zinc, a black deposit of oxide of copper is made on it. This puts the cell in such condition that it will not work satisfactorily until the zinc has been cleaned. When the cell is in operation, the copper sulphate is changed into zinc sulphate so rapidly that it gets no chance to mix with the latter. A gravity battery, therefore, is only satisfactory in the service which keeps it constantly working. For this reason and also because it does not polarize in the least, it is called a closed circuit battery.

There are various other types of batteries in which the third method of depolarizing is used, but which are not in sufficiently general use to make their description desirable here.

**50. Dry Batteries.** — During the last few years, what are called dry battery cells have been coming into quite extensive use for intermittent work. These cells usually have zinc and carbon electrodes, while the electrolyte is in the form of a paste instead of being liquid as in the ordinary cells. Probably the oldest form of dry cell is one invented by Gassner, and shown in Figure 27. The zinc is made in the form of a deep cup and is the containing vessel. In the middle, and occupying probably one-half

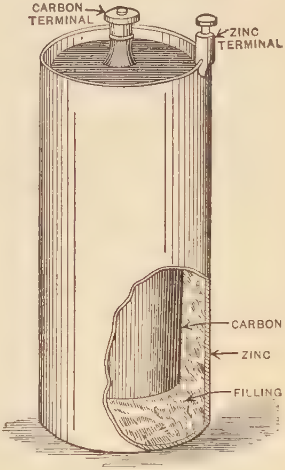

FIG. 27. — Dry Cell, Showing the Filling.

of the space inside the zinc cup, is the carbon electrode. Between the zinc and the carbon a paste is placed which is composed of the following: "Oxide of zinc, one part, by weight; sal ammoniac, one part, by weight; plaster, three parts, by weight; chloride of zinc, one part, by weight; water, two parts, by weight." The oxide of zinc is used for making the paste porous, which permits the escape or combination of gases and hence lessens polarization. This cell has a pressure of 1.3 volts, and will polarize rapidly if kept long in circuit.

A great many dry batteries of different compositions are now on the market, and they have proved themselves very convenient and effective. It is interesting to know that the resort to dry batteries is to a certain extent a return toward Volta's Pile.

**51. Local Action.** — In nearly all battery cells some chemical action, by which the zinc is wasted, goes on when the circuit is open. This may also proceed while the circuit is closed without adding to the useful current in the cell. Such wasteful chemical action is called **Local Action.** It is usually caused by bits of impurity or differences of composition on the surface of the zinc, which form little local cells with the other portions of the zinc, thus continuously eating it away in spots. This action may be seen by placing a piece of ordinary commercial zinc in dilute sulphuric acid, when a chemical action takes place which is similar to that described above in the case of a cell generating a current, and the zinc is dissolved; while, if the zinc is chemically pure (that is, does not contain any impurities), the action does not occur.

Local action is also caused in some cells by differences in the density of the liquid at various parts of the cell. In this case, the zinc near the top of the liquid is ordinarily wasted away, and it may be entirely eaten off.

**52. Amalgamation.** — Local action caused by impurities may be largely avoided by **Amalgamating** the zinc, that is, by **Alloying** its surface with mercury. For this purpose the zinc is cleaned by dipping into a dilute acid solution, and it is then rubbed with mercury, which makes a pasty alloy on its surface. The impurities in the zinc do not readily form an *amalgam* with the mercury and are therefore covered up, while pure zinc is brought to the surface. As the zinc is eaten away, the mercury remains and combines with the zinc below, thus keeping the zinc plate in good condition until it is practically all used.

Zinc plates, or **Zincs** for batteries, are also sometimes cast with a small percentage of mercury in their composition, which is intended to take the place of amalgamation. The mercury seems to cover all impurities and to present only pure zinc at the surface.

**53. Amount of Chemical Action in a Cell.** — The amount of metal, such as zinc, usefully consumed in a cell depends directly upon the number of coulombs of electricity which are permitted to pass through the electrolyte. The amount of hydrogen gas, copper, or other metals liberated from the liquid also depends upon the number of coulombs of electricity which pass through the cell. This may be stated as a general law of electrochemical action: *the amount of chemical action in a cell depends directly upon the amount of electricity which passes through it,* and therefore *the chemical action is the same in all cells of a number connected in series,* since the same amount of current will flow through them all.

The weight of a metal in grammes (metric measure) which is dissolved or deposited when one coulomb of electricity passes through a cell, is called the **Electrochemical Equivalent** of the metal. A table which shows the electrochemical equivalents of various chemical elements is included in Article 65.

**54. Value of Zinc as a Fuel.** — Electric batteries in which a metal is directly consumed by chemical action for the generation of an electric current are called **Primary Batteries.** In nearly all primary batteries the metal which is consumed is zinc. The law of electrochemical action already stated shows that no current can be produced without an equivalent consumption of metal, just as an appreciable amount of heat cannot be given out from a fire without an appreciable consumption of coal or wood.

The consumption of zinc in a battery to furnish electrical energy in the form of an electric current is similar to the burning of coal under a boiler to furnish steam power. It can be readily seen that zinc makes an expensive fuel, even though the consumption of a pound of zinc in a battery produces several times as much energy as is produced by the combustion of a pound of coal in the furnace of a boiler; and batteries in which zinc is consumed cannot be used commercially to furnish electricity where currents of great magnitude are required, as in electric lighting.

For such purposes the battery can never compete with the dynamo driven by a steam engine, unless a cell is invented in which coal may be economically consumed in the place of zinc so that the heat due to the combustion of coal may be thus directly transferred into electrical energy, or a cyclic system is commercially developed in which the metal dissolved in the battery may be recovered through the action of electric currents generated by water power. If this is ever done, the electric battery will displace the steam boiler and engine, but *batteries in which zinc is consumed can never economically furnish current for light and power.*

**55. Where Batteries are Valuable.** — In many domestic operations, such as ringing electric bells, regulating dampers, etc., primary batteries hold an important place. In telegraphy and telephony, and other commercial applications of electricity and magnetism on a large scale in which comparatively weak currents are required, they are used in great numbers. They are also used in electrotherapeutics and similar applications.

For many domestic purposes the work required of a battery is intermittent, and so small that a cell of constant electromotive force is not required. Consequently many batteries are made of simple zinc-carbon cells in which the liquid is a solution of sal ammoniac. These cells are like Leclanché cells without the dioxide of manganese depolarizer. The carbon plate is generally made with a large surface, as illustrated in Figures 16 and 17, so that the polarization is not very rapid.

**56. Storage Batteries.** — If a gravity cell is worked until its solution contains plenty of zinc sulphate, and a current is then passed through it from the copper plate to the zinc plate, metallic zinc will be deposited on the zinc plate by the chemical action due to the current. The current which separates the zinc from the liquid is passed through the cell against the electric pressure naturally developed by the cell, and energy must be expended in order that the current may flow. This energy is stored up during the process, in the deposited zinc, and may be returned when the zinc is again dissolved through the operation of the battery in the ordinary manner.

Alternate **Discharging** of the battery by taking current, and consequently energy, from it through the consumption of zinc, and then again

**Charging** it by expending energy in the cell by sending current into it and depositing zinc, may be kept up indefinitely. Each time the cell is discharged, it gives out as much energy through the consumption of its zinc, as was given to it in depositing the same amount of zinc. There are certain deductions of energy from the external electrical circuit, however, which are inevitably linked with these operations, so that it would be an error for the reader to assume that the **Efficiency** of the cell is one hundred per cent.

A battery in which energy may be stored through the forced chemical action called charging, and from which this energy may be then withdrawn through the natural action of the cells, is called a **Storage Battery**. Storage batteries are also called **Accumulators** or **Secondary Batteries.**

Commercial storage cells are usually made with lead plates immersed in dilute sulphuric acid. When a cell of this type is fully charged, one of the plates, *i.e.* the negative one, is of a grayish color and is practically pure lead with a surface in a more or less spongy state. The other plate is of a brownish or plum color, due to the fact that its surface is covered with a layer of the brownish oxide of lead, or, as it is called, peroxide of lead. When the circuit is closed, a current flows.

The flow of current within the cell is from the gray plate toward the reddish plate, when the cell is being discharged. The electrical pressure of the cell is set up by chemical reactions between the plates and the sulphuric acid, which, when the current flows, change the lead oxide on the red, oxidized plate into sulphate of lead, and at the same time also change the lead of the grey plate into sulphate of lead. The cell continues to give out current until the surfaces of the plates become, to a more or less equal degree, changed into sulphate of lead, and then the pressure falls rapidly, as it will be remembered that similar plates in a solution do not exhibit an electromotive force. Under this condition the battery is said to be fully discharged, and it can be charged up again by passing current through it in the opposite direction.

The charging process is one in which the negative plate is restored to its plain leaden condition, and the positive plate becomes oxidized again. When the negative plate has been reduced to practically plain lead with a spongy surface, the cell is said to be fully charged. In actual work a cell is never allowed to become entirely discharged, as complete discharge is very likely to result in great injury to the plates.

**57. Construction of Lead Cells.** — Since the chemical action which goes on in these storage cells during charging and discharging roughly consists in transferring oxygen, which exists in the oxide or sulphate of lead on the plates, from one plate to the other, it is desirable that the plates be capable of holding a large amount of oxide of lead in order that the cells may be of large capacity; and they are therefore made with corrugations or perforations in which the oxide may be fixed. The perforated plates are called **Grids.**

Sometimes the plates are made up for use by filling the perforations in the grids with a paste consisting of lead oxide moistened with sulphuric acid. This process is called **Pasting**; and plates made up thus are often called **Pasted** plates, or Faure plates after the name of the inventor of the method. Sometimes the oxide is formed by frequent charging and discharging of the cell. This process is called **Forming,** and plates of this kind are called Planté plates, after the original inventor of the lead plate storage battery, who used this method. In the process of pasting it is usual to use the yellow oxide of lead, which is commonly known as litharge, to paste on the negative plates, and the red oxide, which is commonly known as minium, to paste on the positive plates. These turn into plain lead on the negative and peroxide of lead on the positive plates, during the process of charging the battery. Some manufacturers paste both plates with sulphate of lead moistened by sulphuric acid, instead of using the oxides of lead. The sulphate of lead is a white powdery substance which can be bought of dealers in chemicals.

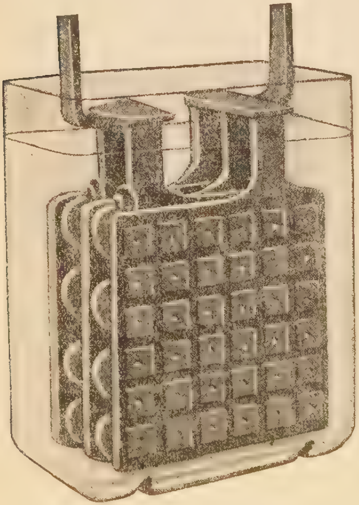

FIG. 28. — Lead Plate Storage Cell.

Figure 28 shows a lead plate storage cell in a glass jar. In place of the jar it is not unusual to use a rubber cell, or a wooden box lined with rubber or lead. In order that the cell may have a capacity for a large current, a number of positive and negative plates are put alternately in one jar and are connected in **Parallel** — that is, the plates are connected so that the current capacity of the cell is equal to the sum of the capacities of the various plates, but the pressure of the cell is the same as that of a cell made up of a single pair of the plates.

The positive plates of a lead plate storage battery usually have a brownish color, and the negative plates a grayish color. The electrical pressure produced by a lead plate cell generally varies between 1.8 and 2.2 volts at different conditions of the charge. The higher value occurs in a fully charged cell, and the pressure falls as the cell discharges.

**58. Other Storage Cells.** — Commercial storage batteries are made with other liquids than sulphuric acid and other than lead plates, but they cannot be given consideration here, as they have not come into common use.

## QUESTIONS

1. How may depolarization be effected by mechanical means?
2. Describe a bichromate cell.
3. Which method of depolarization is used in the bichromate cell?
4. How does depolarization proceed in a bichromate cell?
5. Why must the zinc electrodes be withdrawn from the electrolyte of a bichromate battery when it is not in use?
6. Why are porous cups used in the Bunsen and Grove cells?
7. Describe a copper oxide cell.
8. What causes depolarization in a copper oxide cell?
9. Describe a silver chloride cell.
10. Describe a Leclanché cell.
11. What is the depolarizer in a Leclanché cell?
12. What service is the Leclanché cell fitted for? Why?
13. How is a Daniell cell constructed and of what materials?
14. What method is used in depolarizing a Daniell cell?
15. Is the Daniell cell an open or closed circuit cell?
16. What is the chemical action in a Daniell cell?
17. Why must blue vitriol be occasionally added to a Daniell cell?
18. Why is a porous cup used in a Daniell cell?
19. How does the gravity cell differ from the Daniell cell?

20. Why is the solution of zinc sulphate diluted and the copper sulphate made strong in a gravity cell?

21. Why is a gravity battery short circuited for a time when it is first set up?

22. What is required to prevent diffusion in a gravity cell ? Why?

23. What is the effect of the diffusion of the fluids in a gravity cell?

24. What are dry cells, and how are they constructed?

25. What is local action in a cell?

26. How is local action caused?

27. What is amalgamation?

28. How does the mercury apparently act when an amalgamated zinc is placed in a cell?

29. How may zinc be amalgamated?

30. On what does the amount of chemical action in a cell depend?

31. State the general law for electrochemical action.

32. How much more copper will be deposited in one minute in a Daniell cell through which a current of five amperes flows than will be deposited in a similar cell. through which one ampere flows?

33. If several gravity cells of different sizes were connected in circuit in series, would equal amounts of copper be deposited in each?

34. What are electrochemical equivalents?

35. What are primary batteries?

36. Why cannot primary batteries in which zinc is consumed be used economically to furnish current for lighting and power?

37. Name a number of uses to which primary batteries may be put.

38. What is a storage battery?

39. What happens in a gravity cell when current is forced through it from copper to zinc?

40. Of what are commercial storage batteries made?

41. What is the character of the positive plates in a storage battery when it is charged? When it is discharged?

42. What is the character of the negative plates in a storage battery when it is charged ? When it is discharged?

43. Explain the action in a storage battery when it is discharging, and when it is charging.

44. How are lead plate cells constructed ?

45. What are grids?

46. What is the difference between a pasted and a formed plate?

47. What is meant by the statement that the sets of negative plates (also the positive) in a cell are "connected in parallel?"

48. What are the pressures of a lead storage cell?

# CHAPTER V

## ELECTROLYSIS

**59. Electrolytic Conductors.** — An electric current seems to flow through some liquids in a different way from that in which it flows through solid conductors. In fact, liquids may be divided into three classes on the ground of their action when subjected to the effect of an electric pressure: —

1. Those which appear to be insulators of a high grade, such as paraffine oil, turpentine, etc.
2. Those which conduct like solids, without apparent chemical action, such as mercury, metals in a melted condition, etc.
3. Those in which chemical decomposition occurs when a current flows through them, such as solutions of acids or salts of the metals, and some melted compounds.

Liquids of the latter class are called **Electrolytes**, and the process of their decomposition by electrochemical action is called **Electrolysis**. A cell in which electrolysis is carried on is generally called an **Electrolytic Cell**, or when the electrochemical action is used to determine the strength of the current flowing through the cell, it is called a **Voltameter**, as will be explained later. The plates of an electrolytic cell are called **Electrodes**. The electrode at which the current enters the electrolyte is ordinarily called the **Anode**, and the other electrode is called the **Cathode**. The products of the electrolysis are often called **Ions**.

**60. Action in Electrolytic Cells.** — We will, for a moment, consider the elementary performance of an electrolytic cell in which the electrodes are copper plates and the electrolyte is a solution of a copper salt. The commonest salts of copper are the sulphate of copper, the nitrate of copper, the chloride of copper, the carbonate of copper, and the sulphide of copper. Any salt of a metal is a chemical combination formed by the action of an acid on the metal. Thus, sulphate of copper is a combination which may be formed by the action of sulphuric acid on copper; and nitrate of copper may be formed by the action of nitric acid on copper. Sulphuric acid is a chemical compound of hydrogen with sulphur and oxygen, — the sulphur and oxygen in this case forming what is called an acid radical. The radical of sulphuric acid has a greater chemical attraction, or **Affinity**, for copper than for hydrogen, especially when the acid is hot. Consequently, when copper is immersed in hot sulphuric acid the copper is attacked and dissolved, during which process it combines with the acid radical of a portion of the acid and forms sulphate of copper. The copper sulphate stays in the solution unless means are taken to cause it to crystallize out.

The crystallized copper sulphate, or blue vitriol, as it is often called, may be bought at any drug store. It is in lumps of blue crystals which readily dissolve in water.

If an electrolytic cell is made up by placing copper plates in a vessel containing a solution of copper sulphate in water (Fig. 29), and an electric current from a battery is sent through the cell, the copper sulphate becomes decomposed and metallic copper is deposited on the cathode. The acid radical, corresponding in equivalent amount to the copper which is deposited from the copper sulphate, makes its appearance at the anode, where its chemical activity causes it to combine with the copper of the anode, which it gradually eats away. It is thus seen that the anode is gradually eaten away or dissolved in the solution, while the cathode grows from the deposited copper.

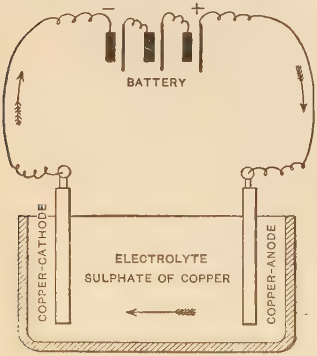

FIG. 29. – Electrolytic Cell with Copper Electrodes and Electrolyte of Copper Sulphate.

This is the way copper plating is done,[1] though the cathode to be plated is not usually made of copper, and it may, indeed, be of any conducting material. During the process of plating, the cathode has deposited upon it a covering of metal, while an equivalent amount of the metal is dissolved into the solution from the anode.

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[1] Article 365.

**61. Action in Electrolytic Cells, Continued.** — In a similar manner, other salts of copper and the various salts of other metals may be **Electrolyzed.** It is even possible to electrolyze liquids which do not contain salts in solution, as in the case of the water voltameter, which will be more fully described later.[1] Here the electrodes are of platinum and are, therefore, not dissolved, but the water is decomposed into its constituent parts, which are hydrogen and oxygen, and these are given off in the shape of bubbles at the cathode and anode respectively.

This action in using up the electrolyte itself is somewhat similar to the action that would have taken place in the copper solution spoken of above, if platinum electrodes had been used. In such a case the copper is, as before, deposited upon the cathode; but the acid radical cannot now act upon the anode, which is incorrodible, so that it attacks the water in the solution, takes hydrogen from the water to make sulphuric acid, and thereby sets oxygen free, which gathers upon the anode in bubbles and escapes. This process continues until all the copper is extracted, after which the reactions become the same as those explained later for acidulated water. It is seen that the electrolyte in this case is decomposed, but that the electrodes are unaffected. In such manner it is possible to make chemical combinations under the influence of the electric current which are of great value to commerce.

*The metal part, or its equivalent in hydrogen, of an electrolyzed solution is always deposited upon or escapes at the cathode;* that is, *it appears to travel with the current* to the electrode where the current leaves the cell. *The acid radical, or its equivalent in oxygen, appears to travel against the direction of the current and is deposited at the anode,* where it may either be given off as gas, or by combining with the anode, it may cause the latter to be dissolved.

**62. Faraday's Laws.** — During the years 1833 and 1834 Faraday occupied his matchless intellect in experimentally investigating the decomposition of electrolytes, such as has been described in the preceding article, by the effect of a current of electricity. An exact knowledge of the more important conditions of electrolysis (which previously was an almost unexplored field of phenomena) resulted from these investigations, and Faraday laid down his principal deductions in two laws, which may be stated as follows: —

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[1] Articles 66 and 156.

1. *When an electric current passes through an electrolyte, the quantity of the liquid decomposed depends upon the amount of electricity, measured in coulombs, that passes through it,* and is independent of the size of the electrodes and the electrical pressure applied to the cell. The amount of chemical action is therefore an exact measure of the number of coulombs of electricity passed through the electrolyte.

2. *When equal quantities of electricity are passed through different electrolytes, equivalent quantities of the electrolytes are decomposed.*

This second law was stated by Faraday thus: — "If the same quantity of electricity passes through different electrolytes, the masses of different ions liberated at the electrodes are proportional to their chemical equivalents."

**63. Chemical Equivalents.** — The phrase "chemical equivalents" used by Faraday means the relative combining proportions, or equivalent quantities in chemical combinations, of the various ions. When chemical elements combine with each other to form compounds, they are supposed to always join the combinations in certain fixed proportions, which are characteristic of the individual elements. Thus, if a quantity of silver weighing 107.9 grammes is dissolved in a quantity of nitric acid that is just sufficient to take it all into solution, then the same quantity of the acid will just dissolve 32.7 grammes of zinc; and the combining weights of silver and zinc in corresponding compounds are always in the ratio of 107.9 to 32.7, so that 107.9 and 32.7 may be called the equivalent quantities in chemical combinations, or the **Equivalent Weights** of these metals. Many of the elements are not confined to a single relation in all of their compounds, but possess two or more combining proportions which are simple multiples of each other. This is true, for instance, of copper, whose usual combining proportions, taken in the same relation as those given above, are 31.8 and 63.6. The "equivalent weights" or "chemical equivalents" of the metals are important factors in electrolytic operations, as is explained in Article 65.

**64. Applications of Faraday's Laws.** — The first of Faraday's laws of electrolysis has already been applied to the operation of electric batteries,[1] and a battery cell is in fact an electrolytic cell in which the process of electrolysis is set up by current in the circuit which results from the chemical activity in the cell itself. The chemical changes occurring through the consumption of zinc in the primary battery cell supply sufficient energy to give a margin for useful purposes outside of the cell; somewhat in the same style, for instance, as fuel is consumed at the boiler of a locomotive for the purpose of converting its chemical energy into mechanical power sufficient to overcome the internal frictional and other resistances of the locomotive, and yet leave a goodly margin of power for use in pulling a train.

The electrolytic cell which is intended primarily for the purpose of decomposing chemical compounds, ordinarily requires, on the other hand, electrical energy to be applied from an external source to set up the chemical decomposition. In fact, there are comparatively few combinations of electrodes and electrolytes that will give out sufficient energy to carry on desired special chemical changes in themselves.

Whether the power which is used for forcing the current through the cell is obtained from the cell itself or from an external source, such as a dynamo or battery, the amount of chemical action caused by the electrical current in a given time is proportional to the current flowing; and the power expended in making a given amount of chemical change is, after transformation losses are deducted, equal to that which would be given out or absorbed were the decomposed elements of the electrolyte joined together again. The storage battery is a good example of this. When the battery is being charged, power is required to send the current through the circuit which makes the chemical changes in the battery. When the battery is being discharged, the constituents of the battery return to their original state, and in doing so give out an amount of power equal to that expended in charging minus the inevitable losses which occur in the circuit.

Faraday foresaw that this must be true, and said that, "If the electrical power which holds the elements of a grain of water in combination" (water is made of two atoms of hydrogen to one of oxygen), "or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine, could be thrown into the condition of *a current*, it would exactly equal the current required for the separation of that grain of water into its elements again."

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[1] Article 53.

**65. Electrochemical Equivalents.** — The second law given in Article 62 means that the amount of chemical change that takes place, when a coulomb of electricity is passed through an electrolytic cell, is dependent upon those characteristics of the elements of the electrolyte which may be called their equivalent weights.

If, then, we have weighed the amount of silver that is separated from a silver solution by the passing of one coulomb, and if we know the equivalent weights of the various metals, we can calculate the amount of any other metal that will be separated under similar circumstances, by merely multiplying the weight of the silver separated by the ratio of the equivalent weight of the other metal to that of silver.

The weight of a material that is separated from an electrolyte by one coulomb of electricity is called its **Electrochemical Equivalent**. The electrochemical equivalents of a few of the chemical "elements" have been determined by direct measurements, and others by calculation from their relative combining proportions.

The following is a table of the values of the usual electrochemical equivalents for a number of the chemical elements: —

| IONS | Electrochemical Equivalents in Grammes per Coulomb | Relative Combining Proportions or Equivalent Weights |
|---|---|---|
| Aluminum | .0000936 equals K times | 9.04 |
| Copper, I | .000659 " K " | 63.6 |
| Copper, II | .000329 " K " | $\frac{1}{2} \times 63.6$ |
| Gold | .000681 " K " | 65.7 |
| Hydrogen | .0000104 " K " | 1.008 |
| Iron, II | .000290 " K " | 28.0 |
| Iron, III | .000193 " K " | $\frac{2}{3} \times 28.0$ |
| Lead | .00107 " K " | 103.4 |
| Nickel | .000304 " K " | 29.4 |
| Nitrogen | .0000485 " K " | 4.68 |
| Oxygen | .0000829 " K " | 8.00 |
| Silver | .001118 " K " | 107.9 |
| Tin, II | .000616 " K " | 59.5 |
| Tin, IV | .000308 " K " | $\frac{1}{2} \times 59.5$ |
| Zinc | .000338 " K " | 32.7 |

The value of K in this table is equal to the electrochemical equivalent of any one of the elements divided by the corresponding equivalent weight. Its numerical value is .00001036. The values of the equivalents for silver are those which are most accurately known.

It is noticed that two values are given in the table for tin, for iron, and for copper. This is because each of these metals has different chemical equivalents in two classes of compounds of common occurrence. The second value of the electrochemical equivalent of copper, *i.e.* .000329, is the value which usually applies when copper is deposited in an electrolytic cell. The table may be reduced to common measure for service in electroplating, etc.,[1] by the knowledge that one gramme (Metric Measure) is equal to 15.432 grains, or, approximately, thirty-five thousandths of an ounce.

### PROBLEMS

*A.* How many ounces of silver will be deposited by 100,000 coulombs of electricity? *Ans.* 3.91 oz. (approx.).

*B.* How many ounces of copper will be deposited by 1,000,000 coulombs of electricity from a copper solution having an electrochemical equivalent of .000329? *Ans.* 11.5 oz. (approx.).

*C.* How many ounces of aluminum will be deposited from a suitable electrolyte by 100 amperes flowing for one hour? *Ans.* 1.18 oz. (approx.).

*D.* How many ounces of zinc does a Daniell cell consume in generating $\frac{1}{4}$ of an ampere of current for 3 weeks continuously? *Ans.* 5.35 oz. (approx.).

*E.* How many ounces of acidulated water will 50 amperes flowing for 5 hours decompose? *Ans.* 2.94 oz. (approx.).

**66. Electrolysis of Acidulated Water; Water Voltameter.** — Pure water is a non-conductor; but if a little sulphuric acid is added, it becomes a conductor, and it may then be decomposed by electrolysis. The acid is first decomposed, and that in turn decomposes the water, but the effect is the same as if the water were originally decomposed. An apparatus such as that illustrated in Figure 30 may be used very nicely for showing the relation between the electrochemical equivalents of hydrogen and oxygen. The tubes *A*, *B*, and *C* are filled with the acidulated water and the cocks closed. When the current is turned on, it flows through the water between the electrodes *EE*, and the water is decomposed so that oxygen collects in *A*, forcing the water down; and hydrogen collects in *B*, also forcing the water down. The figure shows that there is almost twice the volume of the latter as of the former.

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[1] Chapter XXII.

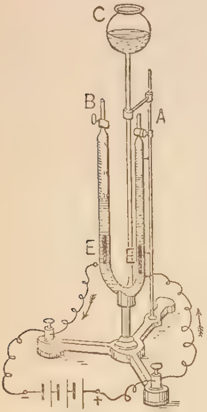

FIG. 30. — Water Voltameter.

To show why the liberated gases come off in these proportional volumes, it should be explained that a given weight of hydrogen occupies about sixteen times as much bulk or volume as an equal weight of oxygen when they are under equal pressures. Looking at the table of the preceding article, it is seen that one coulomb of electricity liberates about one-eighth as much hydrogen by weight as of oxygen. Therefore, when a given weight of hydrogen has been generated in the voltameter, eight times as great a weight of oxygen has appeared in the other tube. But, because of the smaller bulk of a given weight of oxygen as compared with hydrogen, the amount of oxygen liberated will only fill about one-half as much space as the hydrogen. The distance the liquid is pressed down in the hydrogen tube is a little greater than twice that in the other, because some of the oxygen is dissolved in the water.

**67. Theory of Electrolysis.** — The reason why chemical changes take place in an electrolytic cell has not as yet been satisfactorily explained, though many plausible suggestions have been made. Probably the one most usually accepted is the theory of **Electrolytic Dissociation**. The first at all satisfactory step toward this theory was suggested by Grotthuss in 1805. He believed that the metallic parts of a salt were charged with a positive charge of electricity, and were attracted by the cathode, while the non-metallic parts were attracted in the opposite direction towards the anode. He considered that the current flowing through the liquid decomposed it, and that the parts were then caused to move to the electrodes by these attractions. Figure 31 represents his conception, which is intended to illustrate his idea of the action of the current upon water. The ovals in the figure indicate molecules, or infinitely small masses of the water. The squares marked with a + sign represent the hydrogen atoms, and those marked with a — sign represent the oxygen atoms, which are supposed to compose the molecules of the water, and which are held together by the attractions of their electric charges. When the electrodes are charged, the molecules take the positions shown in the figure. The positive charge on a hydrogen atom next to the cathode is neutralized by the negative charge on the plate. This atom is thus released from its neighboring oxygen atom and escapes. The freed oxygen atom then combines with the hydrogen in the next molecule, the oxygen of that molecule going to the next, and so on. The last oxygen atom is freed, as was the hydrogen, by contact with the anode. New molecules have now formed as indicated by the brackets, and the process of breaking up and re-combining is continued.

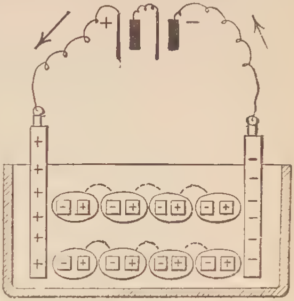

FIG. 31. — Illustration of the Arrangement of Molecules of Electrolyte as supposed by Grotthuss.

Since a negative atomic charge has been given to the anode, and a positive charge to the cathode during the process described, a current must flow through the wire connecting the terminals of the cell, as shown by the arrows, to equalize the potentials, and the electricity continues to be transferred through the cell by this exchange of the atoms.

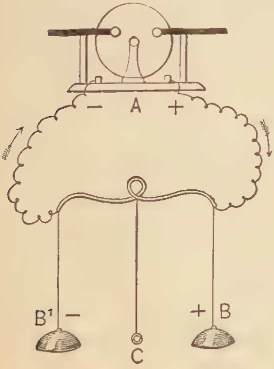

FIG. 32. — Electric Chimes. Analogy to the Theory of Electrolysis.

The supposed transfer of electricity from electrode to electrode by the atoms, may be likened, by analogy, to the **Electric Chimes** invented by Franklin in 1752. Figure 32 represents an apparatus somewhat similar to that of Franklin. *A* is an electrical machine, *BB′* are two bells mounted near together but insulated from each other, and *C* is the tapper, supported by a silk thread. If *C* is touched to *B*, it is given a positive charge and is repelled by *B* and attracted by *B′*. Flying over to *B′*, the charge of *C* is reversed by contact with $B'$, and it swings to $B$ again. Thus the tapper continues to journey back and forth between $B$ and $B'$, carrying a positive charge each time from $B$ to $B'$ and returning with a negative charge from $B'$ to $B$. The machine $A$ keeps up the charges on the bells by the current indicated by the arrows, just as the electric battery, $B$, keeps up the current through the electrolytic cell of Figures 31 and 33. The bells are in metallic connection with the machine by means of wires.

In the analogy with Grotthuss' explanation of the action in the electrolytic cell, we must think of the bell tappers as infinite in number, and charged from an external source; while as soon as they tap upon the electrode (the bell) they escape. The continual transfer of electricity from electrode to electrode is, however, of a similar character to that performed by the "chimes."

Clausius, about 1857, found that this theory would not explain all the phenomena encountered in electrolysis. He considered that Grotthuss' explanation of the transfer of electricity was satisfactory, but asserted that a sufficient cause did not exist to incite the breaking up of the molecules as described. He therefore presented another hypothesis, to the effect that when a salt is dissolved or diluted in water some of the molecules are dissociated, or broken up into their component atoms, by the process of solution. If common salt (which is a compound of metallic sodium and chlorine) is dissolved in water, some of the molecules of the dissolved salt are broken up into their atoms, Clausius asserted, and the solution therefore contains some complete molecules of salt and also some free atoms of sodium and of chlorine. Figure 33 illustrates the case, where the ovals represent the complete molecules and the squares the free elements. The positive squares in this case represent sodium, and the negative ones represent chlorine. Clausius held that the electrolytic action now goes on by the free atoms discharging at the electrodes as assumed in Grotthuss' theory.

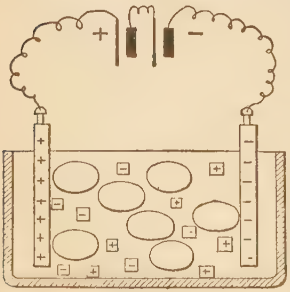

FIG. 33. — Illustration of the Arrangement of Molecules and Atoms in a Solution, as supposed by Clausius.

This theory, which has strong experimental evidence for its support and has been greatly extended by various noted scientists working within the past two decades, has done much to aid in the development of electrochemistry by affording experimenters a reasonably satisfactory basis from which to examine the character of their work; but recent investigations have thrown doubt upon its truth. The reader must remember that it is only a theory to be used for the purpose of gaining a graphic idea of the processes of electrolysis, and may therefore be looked upon as akin to an analogy to be used, like the hydraulic analogy to the flow of electric current, only for the purpose of clear illustration.

## QUESTIONS

1. What two kinds of electrical conduction are there?
2. What effect has an electric current upon solutions of salts and acids?
3. What is an electrolyte?
4. What is electrolysis?
5. What is an electrode?
6. What are the two electrodes of an electrolytic cell called?
7. What are ions?
8. How may the salt of a metal be obtained?
9. Describe the action when a current is sent through an electrolytic cell which has copper plates dipped in a solution of copper sulphate.
10. To which electrode do the metal ions go?
11. What happens, in a cell having platinum electrodes and a solution of copper sulphate, when a current passes between the electrodes?
12. When did Faraday make his investigations on the decomposition of electrolytes?
13. What is Faraday's first law of electrolysis?
14. What is the chemical action in an electrolytic cell proportional to?
15. How many more grammes of material will be decomposed by 25 coulombs than by 5 coulombs?
16. What is Faraday's second law?
17. What does Faraday's second law mean?
18. What is meant by "chemical equivalent"?
19. Compare a primary battery cell to an electrolytic cell.
20. How much energy is required to produce the chemical action which occurs in an electrolytic cell?
21. What is the electrochemical equivalent of a substance?
22. A gramme is what part of an ounce?

23. Describe how oxygen and hydrogen can be separated from acidulated water.

24. Why is the bulk of hydrogen liberated by the decomposing of water twice as great as the bulk of oxygen liberated?

25. In decomposing water, how much more weight of oxygen is liberated than of hydrogen? Why?

26. What is meant by the theory of electrolytic dissociation?

27. What did Grotthuss do in the development of the dissociation theory? When?

28. Illustrate Grotthuss' conception of the action in a cell.

29. Give a mechanical or electrical analogy to the action in a cell, as explained by Grotthuss (electric chimes).

30. What is Clausius' hypothesis regarding electrolytic action? When did he advance it?

31. Has the electrolytic dissociation theory been proved?

# CHAPTER VI

## THE NATURE AND PROPERTIES OF MAGNETISM

**68. Historical Facts Concerning Magnetism.** — The true nature of magnetism seems to be very closely connected with that of electricity, and it will probably not be exactly known till the exact nature of electricity is determined. The word **Magnet** probably comes from the Greek word for the country of Magnesia, which is a small division of Ancient Greece, where a deposit of magnetic iron ore or **Lodestones** (also called loadstones) was known to the Greeks.

Some of the properties of magnets were known long before the Christian era. It is said that the Chinese used a device similar to the compass to guide their way across the plains of Tartary many centuries before the birth of Christ, but this is not probable. In Europe the use of the compass did not become general until the thirteenth century of the Christian era. The attractive power which magnets have for iron is mentioned by many early writers: Plato, Euripides, and Thales (the Greek philosopher referred to in Article 1), all speak of the lodestone or magnet. Dr. Gilbert, who laid the foundation for our words "electrical" and "electricity," made a great many experiments with magnets and magnetic materials, and was the first to recognize that the earth is a great magnet.

**69. Artificial and Natural Magnets.** — Lumps of iron ore composed of a certain oxide of iron which is called **Magnetite** or magnetic ore, when in a pure form, sometimes have the peculiar property of attracting pieces of iron, and they are then called lodestones. The property held by the lodestone is called **Magnetism**, and the body having the property of magnetism is called a **Magnet**.

The action of magnets led some of the earlier experimenters to look upon magnetism as due to a magnetic fluid, but this idea has been proved to be wrong. It is found that pieces of steel which touch a lodestone, or other magnet, become magnets without any loss of the magnetic virtue from the original magnet,—which would not be possible if magnetism were an ordinary fluid. Magnets made thus by touching are sometimes called **Artificial Magnets**, and lodestones are called **Natural Magnets**. When pieces of soft iron touch a magnet they also become magnets, or are **Magnetized**, while in contact with the magnet; but when separated from it the magnetism of the soft iron disappears. This is called **Temporary Magnetism**, while the magnetism of hard steel which remains permanently is called **Permanent Magnetism**.

**70. North and South Poles and the Magnetic Needle.**—When a magnet is suspended on a pivot or a thread, it sets itself in a direction so as to point nearly north and south; and in our country, if it is pivoted at the centre, the north end dips down as though it were heavier than the south end. A small elongated magnet thus suspended is called a **Magnetic Needle** (Fig. 34). If a magnetic needle is turned from the direction which it naturally takes when free to swing horizontally on its pivot, it will at once return, swinging to and fro until it settles down in its original position.

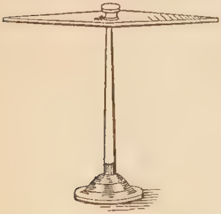

FIG. 34.—Magnetic Needle.

The pole of a suspended needle which points to the north is called the **North Pole**, and the other pole is called the **South Pole**. This tendency of a magnetic needle to set itself north and south is the foundation of the compass, which essentially consists of a magnetic needle mounted over a dial. It is usual in compasses to counterbalance the needle, or pivot it so that it will hang horizontally, but **Dip Needles** are sometimes constructed by mounting magnetic needles on horizontal pivots (Fig. 35). When a dip needle is turned north and south, in our country its north pole turns to a certain degree down toward the earth, as already explained.

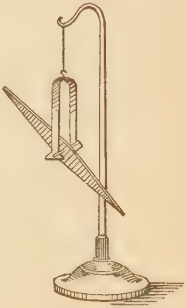

FIG. 35.—Dip Needle.

The north pole of a magnet is often called the **Positive** or **Plus** (+) **Pole**, and the south pole is often called the **Negative** or **Minus** (−) **Pole**. Since the north or positive pole turns toward the north, it is sometimes called the **North-seeking Pole,** and the south or negative pole is sometimes called the **South-seeking Pole.**

**71. Variation of Compass and Dip Needles.** — It was originally supposed that a magnetic needle always pointed toward the same point on the earth, that is, that it always pointed in a direction which was fixed with respect to the true north. But Columbus made a discovery on his first voyage to America which upset the old ideas. His sailors discovered, to their great excitement and fear, that the direction of their ships' compass needles gradually changed as the ships sailed along. The needles kept pointing more and more away from the direction of the North Star, and the sailors became greatly alarmed on account of this most unexpected state of affairs. Had they known what we now know, — that the earth is, in effect, a great magnet, and that its magnetic poles do not exactly correspond with the geographical poles, — they would have had no cause for alarm. As it was, their discovery of a difference at different parts of the earth's surface in the variation of the magnetic needle, from the direction of the true north, made an important contribution to our present knowledge of the earth's magnetic effects.

The dip of the needle also varies from place to place. At the region on the earth called the north magnetic pole, the needle stands with its north pole down and its direction straight to the earth, or the dip is 90°. As the needle is carried farther and farther away from the earth's pole the dip becomes less, until the earth's magnetic equator is approached, where the needle stands in a horizontal position, or the dip is zero. If the needle is now carried farther south it comes more directly under the influence of the earth's south magnetic pole, and the south pole of the needle dips down.

**72. Magnetic Attraction and Repulsion.** — If a pole of a magnet is brought near a magnetic needle it is found to attract one pole of the needle and repel the other pole. The north pole of the magnet may be determined by noting the way it stands when suspended by a thread, and it will then be found that *the north pole of the magnet always repels the north pole of the needle and attracts the south pole of the needle.* The south pole of the magnet acts in an exactly opposite manner.

This action shows that *there are two kinds of magnetic poles*, and that *poles of the same kind repel each other and poles of opposite kinds* *attract each other.* This is quite similar to the law of attractions and repulsions of electric charges given in Article 4. Now that we know this law of magnetic attraction and repulsion, we understand why the attractions of the great earth magnet cause magnetic needles to take certain positions as described in the previous paragraphs.

**73. Induced Magnetism.** — If the experiment with a magnetic needle, described in the paragraph above, is repeated, but a bar of soft iron is used in place of the magnet, it is found that *either end of the iron bar attracts either pole of the needle.* If the iron bar is laid with one end near the pole of a magnet, it may be shown to be magnetized by moving a magnetic needle around it. The needle will show by its action that the end of the iron bar which is near the magnet pole has become a pole of sign opposite to that of the magnet pole, and the farther end of the bar has become a pole of the same sign as that of the magnet pole. The bar is said to be **Magnetized by Induction.**

The magnetism in the iron bar becomes stronger as it is brought closer to the magnet pole. The magnetism induced in a bar of iron may induce magnetism in another piece, and this in another piece, and so on; and thus a magnet may be made to support a string of several nails end to end, each of which has become a magnet by induction (Fig. 36). But the magnetism in each successive piece is weaker than in the preceding piece.

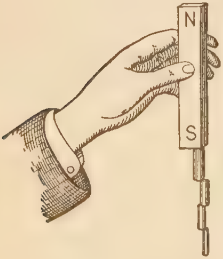

FIG. 36. — String of Nails magnetized by Induction and suspended End to End from a Magnet.

We are now in a position to see why a magnet attracts a piece of iron, and the cause for the effect of the iron bar on the magnetic needle. When a steel magnet pole is brought near to a piece of iron, the iron is magnetized by induction. The positive and negative poles induced in the iron are of equal magnitude or strength. One of the induced poles is attracted and the other is repelled by the steel magnet pole, but that which is attracted is nearest the original magnet pole, and the force of attraction is therefore greater than the force of repulsion. The effect of a bar of iron on a magnetic needle is caused in the same way by the magnetism induced in the bar by the poles of the needle.

**74. Every Magnetic Body contains Two Poles of Opposite Signs.** — 1. For every pole induced in a piece of iron or steel, another equal pole is produced. For instance, if the north pole of a magnet is touched to one end of a bar of iron, a south pole is induced in that end and an equal north pole in the other end. 2. If the two ends of the iron bar are touched at once by the north poles of two equal magnets, south poles are induced in both ends of the bar. In this case an examination of the bar with a magnetic needle shows that a north pole, which is equivalent to two poles, is produced near the centre of the bar, and this pole in the middle is called a **Consequent Pole.** 3. Again, if a magnet is broken, it is found that each piece has two equal and opposite poles.

We are therefore justified in saying that *for every magnet pole that exists, there also exists in the same magnetic body an equal and opposite pole.* This is quite similar to the existence along with every electric charge of an equal and opposite charge, as is explained in Article 5.

Magnetic force acts through a vacuum and through all materials except those in which magnetism may be induced.

**75. Magnetic and Non-magnetic Materials.** — Material in which magnetism may be induced, and which is therefore attracted by a magnet, is called **Magnetic Material.** Iron, in its various forms (such as wrought iron, cast iron, and steel), is the most strongly magnetic material known. There are only a few other materials that are known to be magnetic. Of these the metals called nickel and cobalt are the commonest. Manganese, platinum, some of the salts of magnetic metals with their solutions, and oxygen are more or less magnetic, though usually to a very slight degree. All materials which are not quite strongly magnetic are usually spoken of as **Non-magnetic**, since they are nearly neutral as regards magnetism. Magnetic materials are sometimes called **Paramagnetic**, and non-magnetic materials are sometimes called **Diamagnetic**, but these terms have also additional scientific meanings which need not be discussed here.

Whenever magnetic material is needed in the useful arts, iron in its various forms, such as cast iron, wrought iron, and steel, is almost exclusively used on account of its great magnetic qualities. In fact, other materials, except nickel and cobalt, may be considered to be practically neutral when compared with iron.

**76. Forms of Magnets and Methods of making Them.** — Magnets may be made of almost any form. Those made of straight pieces of steel are called **Bar Magnets** (Fig. 37), and those with poles bent nearly together, **Horseshoe Magnets** (Fig. 38). A magnet made in the form of a thin disk, which is magnetized so that its two flat surfaces are the poles, is called a **Magnetic Shell.** The latter is not a very useful form except for theoretical scientific discussions. Electromagnets, which will be treated later, may be found in a great variety of forms, depending upon the duty which they are intended to perform. In making permanent magnets of large cross section, it is common to lay several thin magnets one upon the other. This, as will be seen later, makes stronger poles. A good permanent magnet so made should be able to lift twenty times its own weight.

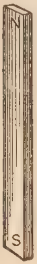

FIG. 37. — Bar Magnet.

A steel bar may be magnetized by rubbing one end with the north pole of a magnet, and the other end with the south pole; or two magnets may be used, stroking the bar with both at the same time, from the middle outward, using opposite poles. Much stronger results may be obtained, however, by placing the steel bar against a strong electromagnet; but the ends of the bar should be joined by a piece of soft iron or the electro-magnet discharged before the steel bar is removed, lest the induced magnetism be partially destroyed in the process of drawing the bar away. The bar may also be magnetized by placing it within a coil of wire through which a current of electricity is flowing.

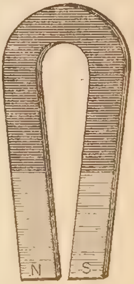

FIG. 38. — Horseshoe Magnet.

**77. Demagnetization and Effect of Heat.** — Any jarring of a magnet will tend to cause its magnetism to disappear, or to **Demagnetize** it. A few sharp strokes of a hammer or the scratch of a file may cause the greater part of the magnetism to disappear; also if the magnet is heated to a temperature about red heat, it becomes demagnetized, and the iron at the same time loses its magnetic quality and does not regain it until it cools to a lower temperature. Cooling a steel magnet seems to increase its magnetism slightly. The effect which is caused upon the magnetic quality of nickel and cobalt by heating them is similar to the effect on iron, but these metals lose their magnetic quality at lower temperatures. The reason for this curious effect is entirely unknown, but it is supposed to come about through some action on the molecules of the material. Some very curious results may be produced in the magnetic qualities of certain grades of nickel steel and other steel alloys by heating and cooling them.

As a magnet loses its magnetism so readily through handling, the horseshoe form is usually furnished with a *keeper*. The keeper is a piece of soft iron which may be placed across the poles of the magnet. This makes a complete magnetic circuit for the magnetism, and tends to prevent its destruction.

**78. Coercive Force.** — It is found that some materials are more readily magnetized and demagnetized than others. It is well known, for instance, that soft iron is very readily magnetized, but loses almost all of its magnetism if it is slightly jarred after the external magnetizing force is withdrawn.

Hard steel is usually more difficult to magnetize, but it retains its magnetism quite strongly. Generally speaking, the harder the steel the more difficult it is to magnetize, and the more strongly it retains its magnetism. We are driven, then, to the belief that there is some force that opposes the magnetization of magnetic materials and also opposes their demagnetization. This force, which is supposed to hinder changes of magnetic strength or condition, is called **Coercive Force**, and it is much stronger in hard steel than in soft iron. The effect of the coercive force is counteracted to some extent by anything that is likely to make the molecules vibrate, such as rough handling, heating, etc. As has already been said, heating to a red heat will cause a magnet to lose all of its magnetism, and a magnet which is dropped on the floor a few times will lose much of its magnetism.

**79. Saturation.** — When a magnet is magnetized as strongly as possible, it is said to be **Saturated**, and when the magnetism has reached this point it will generally grow weaker for a certain time after magnetizing, if the magnetizing force is removed and the magnet is left alone, till the magnetism finally becomes permanent in strength. Such permanent magnets, which have lost the temporary magnetism due to saturation, are very useful parts of many electrical instruments where a constant magnetic effect is important; so that **Aged** magnets, as they are called, are regularly manufactured. They may be artificially aged by immersing in steam for a considerable time.

**80. Distribution of Magnetism.** — The poles of a long bar magnet are not entirely gathered at the ends, but extend some distance along the sides as indicated by the iron filings in Figure 39. If the bar is very long and not made of homogeneous material, several consequent poles may appear (see Figure 40), much as would be the case if the bar were made up of several magnets with their several like poles together. If a very large block or sheet of steel is touched at different places by a magnet pole, poles will appear at the points touched. If a horseshoe magnet is closed at the poles by a piece of iron (called a keeper) very little of the magnetism will be evident, as will be explained later. In

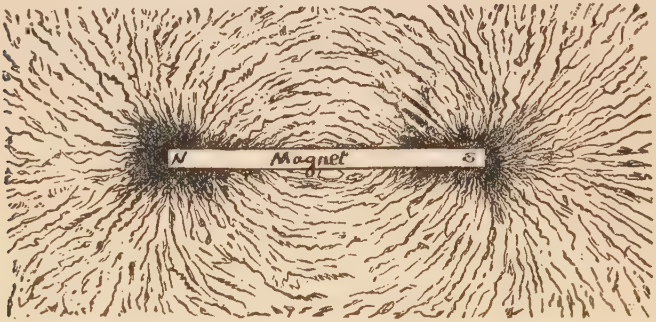

FIG. 39. — Picture of Iron Filings showing the Distribution of Magnetism about a Bar Magnet.

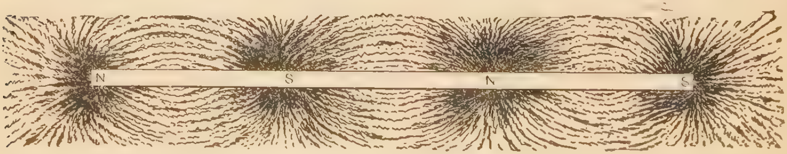

FIG. 40. — Picture of Iron Filings showing the Distribution of Magnetism about a Bar Magnet with Two Consequent Poles.

magnetizing hard steel the *surface only* is likely to be much affected; therefore, in making a permanent magnet having a large cross section, it is advisable, as was suggested above, to fasten together a number of thin magnets. Such a magnet is said to be **Laminated.**

## QUESTIONS

1. What is the probable derivation of the word magnet?
2. In what century did the use of the magnetic needle become usual?
3. What is a lodestone?
4. What is magnetism?
5. What is a magnet?
6. What happens to a piece of steel when it is touched by a piece of lodestone?
7. What happens to a piece of soft iron when it is touched by a piece of lodestone?
8. What is temporary magnetism?
9. What is permanent magnetism?
10. What is a magnetic needle?
11. What position does a magnetic needle take in America when allowed to swing free in all directions?
12. What are the ends of the magnetic needle respectively called?
13. What is a compass? A dip needle?
14. What discovery did Columbus make with reference to the magnetic needle?
15. If the north pole of a magnet is brought near a magnetic needle, what results?
16. If two south poles are brought near together, how will they act?
17. State the law which magnet poles follow in their action upon one another.
18. What is magnetic induction?
19. If a piece of soft iron is brought near the positive pole of a magnet, what kind of a pole is induced in the iron nearest the magnet pole?
20. Why will either pole of a magnetic needle be attracted to a soft piece of iron?
21. Can a single pole exist alone?
22. What is a consequent pole?
23. Need the poles of a magnet be only at the ends of a steel bar?
24. What materials will magnetic forces act through?
25. What are the known magnetic materials?
26. What is the meaning of paramagnetic?
27. What is the meaning of diamagnetic?
28. What are bar magnets? Horseshoe magnets?
29. What is a magnetic shell?
30. Name a number of ways by which a steel bar may be magnetized.
31. About how much should a well made steel magnet lift?

32. If a magnet be struck by a hammer, what is likely to happen?
33. What happens if a magnet is heated red-hot?
34. Will a magnetic needle be attracted by a piece of red-hot iron?
35. What is a keeper? What is it for?
36. What is coercive force?
37. Which is the harder to magnetize, soft iron or steel?
38. Which has the greater coercive force, soft iron or steel?

**81. What is Magnetism?** — We do not know what magnetism is, but we know a great deal about its effects (all of which has been learned by experiments and experience), and we have theories about its real nature. Scientific theories, it must be remembered, are nothing more than shrewd guesses at the secrets of nature, — the guesses being based on the foundation of all that we know, — and these theories are being continually altered and improved as more facts are learned by experience. The earliest theories which offered fairly complete explanations of the various phenomena of magnetism were outlined by Coulomb (after whom the unit quantity of electricity, the coulomb, was named), about 1785, and by Poisson (a great mathematician of France), about 1821. They were followed by a host of others which return more or less satisfactory results when put to the test of experiment. Since, into however many pieces a magnet may be broken, each piece shows a north and south pole, it has long been considered that magnetism is molecular in nature; that is, that the smallest particles or molecules, into which the material can be theoretically divided, are little magnets, each of which has its own north and south poles. So that the theories in regard to the nature of magnetism, that have been proposed from time to time, are all based upon this idea of "polarization" in the molecules of magnetic material.

The theory of Coulomb, which was used and extended by Poisson, regarded all molecules as containing equal parts of two magnetic fluids, one called "Austral," or southern, and the other "Boreal," or northern, which were supposed to be equally mixed under ordinary conditions. But when the molecules were brought within the influence of a magnet, the fluids were supposed to separate and occupy opposite halves of the molecules and so produce magnet poles at each end of the piece of influenced magnetic material. This theory had many faults, and was soon replaced by one proposed by Ampère (another great Frenchman) about 1830. In Ampère's theory, each molecule of magnetic material is supposed to be magnetized by an electric current which flows around it. When a bar of magnetic material is not magnetized, the molecules are supposed to be arranged haphazard, but in such order as to neutralize each other in external magnetic effect. When the material is placed near a magnet pole, the molecules are supposed to be swung around by its attraction or repulsion until their axes are approximately parallel and their like poles all pointing one way. Experimental facts indicate that it is doubtful whether such an electric current can circulate about the molecules, and there is no good reason to believe that it does, and so this theory may also be discarded.

The theory that is now generally accepted, and which seems to more nearly apply to the true condition of the molecules, was first advanced by Weber, about 1852, and was used by Maxwell in his profound mathematical investigations. In this theory the molecules of magnetic matter are supposed to be *magnets by nature*, that is, they are supposed to have natural magnetic poles which are just like those of ordinary magnets, but of course they are very small ones; and we therefore say that magnetic attractions between bits of magnetic material, whether they are large or small, are just as natural as the attractions between bodies which we call gravitation. Now, when magnetic material is unmagnetized it is supposed that the molecules are arranged in a haphazard manner, or in haphazard groups, so that they neutralize each other's external magnetic effects; but when the material is subjected to the influence of magnetic force, the molecular magnets are all attracted around so that their poles point more or less in the same direction. In Figure 41 the small blocks may be taken to roughly represent the magnetic molecules very highly magnified, and all turned in the same direction so that the two ends of the bar are magnet poles. The dark ends represent the south poles and the light ends the north poles of the molecules. When the particles are arranged with their like poles all pointing in the same direction as in the figure, it is seen that the poles

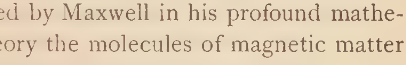

FIG. 41. — Illustration of Arrangement of Magnetic Molecules in highly Magnetized Iron.

in the interior of the material are facing each other in pairs, north to south, and must therefore neutralize each other's effects, but unneutralized poles exist at the ends of the material.

**82. Unit Magnet Pole.** — In order to know the strength of a magnet, some unit of measure must be used; and so we say theoretically that if two small similar magnet poles placed exactly one centimeter (metric measure) apart repel or push each other with a force equal to what is called a **Dyne**, they are *magnet poles of unit strength* or **Unit Poles**. In speaking of a unit pole in this way, it is supposed that the pole is in effect gathered at a mathematical point, while its accompanying pole of opposite sign on the same magnet is at such a distance as to be unaffected by the attraction and repulsion. The condition here described can never be physically produced.

**83. Force exerted between Two Magnet Poles.** — The actual force exerted between two magnets depends upon the strength of their poles and their distance apart. If it were possible to have two separate magnet poles of small size, as compared with their distance apart, the force exerted between them would be *equal to the product of the strengths of the poles divided by the square of their distance apart*. This is similar to the law of the force exerted between two small isolated bodies holding electric charges.[1]

The condition required for the law of force to be fulfilled can only be gained by using poles of two very long, thin magnets. The force between two actual magnets as it may usually be measured does not follow this law directly, because the poles are of considerable size as compared with their distance apart. Every small portion of the pole of one magnet exerts a force on every small portion of the pole of the other magnet, in accordance with the law; and when all these small forces are added together the law is apparently changed, though it is based on the fundamental one.

There are certain similarities which may be perceived between the actions of magnets and of charged bodies, but there are also marked differences, so a close relationship is not evident. There is, however, a remarkably close relationship between magnetism and current electricity, which will be described in a later chapter.

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[1] Article 11.

**84. Magnetic Fields.** — Any open space in which there is magnetism and consequently magnetic force, is called a **Magnetic Field** or a **Magnetic Field of Force.** The magnitude or intensity of the magnetic force at any point is called the **Strength of the Field** at that point.

If an independent north pole could be placed in front of the north pole of a magnet, it would be repelled by the latter pole and be attracted by the south pole of the magnet. This would cause the independent pole to move away from the magnet's north pole and towards its south pole, but as it moved it would continually change its relative distance from the two poles, and the relative magnitude of the forces exerted upon it by the two poles would vary. The direction of the motion of the independent pole would depend upon the relative direction and magnitude of the forces which the two poles of the magnet exerted on it at every point. The actual path would be a curved line very much like the line *AB* in Figure 42. An independent south pole would move in an opposite direction, of course, but over a similar path.

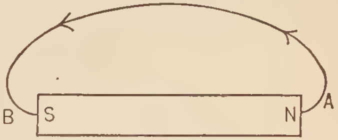

FIG. 42. — A Line of Force set up by the Magnet *NS*.

As already explained, it is impossible to have an independent magnet pole, but for this experiment the companion pole may be sufficiently far removed to satisfactorily show the action.

A shallow glass dish containing a little water may be placed over a magnet (Fig. 43). By properly sticking a magnetized sewing-needle in a cork, it may be floated upon the water in a vertical position with one of its poles close to the bottom of the dish. Then the upper pole will be so much farther away from the magnet than the lower one that the latter will be affected by the force due to the magnet almost as would an independent pole. If the lower pole of the needle is a north pole, it will tend to move through the water, when placed in front of the north pole

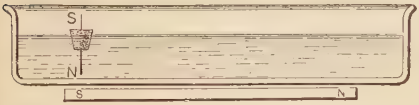

FIG. 43. — Experiment to illustrate the Movement of a Free Magnet Pole when in the Presence of a Bar Magnet.

of the magnet, in a curved line away from the north pole and toward the south pole. If the lower pole of the needle is a south pole, it will tend to move from the south pole toward the north pole. This is exactly as already explained for an independent magnet pole. The experiment here outlined, and which may be so readily tried, is more striking when the magnet is a strong electromagnet such as will be explained later, because the force (acting on the floating needle to move it) is then greater.

The direction of the force at different points of the magnetic field which is around a magnet may be shown by another simple experiment. A sheet of paper may be laid over the magnet and iron filings sifted over it. Now if the paper is lightly tapped the filings will arrange themselves in curved lines like those shown in Figure 39, all of which converge toward the two poles. If the figure were sufficiently large it would be approximately shown that every line which starts out from one pole finds its way round to the other pole. The lines of iron filings may be easily fixed in position if the paper is paraffined before using it, by simply passing the flame of a Bunsen gas burner over it. This softens the paraffine and the bits of iron stick fast.

A magnetic field exists all around a magnet exactly like that which is shown by these experiments in one plane. This may be proved by hanging a short magnetized sewing-needle on a light thread and bringing it near a magnet (Fig. 44). The needle will take a position at every point so that its direction is tangent to the direction which a line of iron filings would take at the same point. The reason for the needle taking this position is because its north pole tends to go one way and its south pole the other, so that the needle turns around until the pull on the two poles is in a direct line through the length of the needle. The iron filings used in the experiment described above, are nothing more than little magnets created by induction, and they take up their position for the same reason that the needle does.

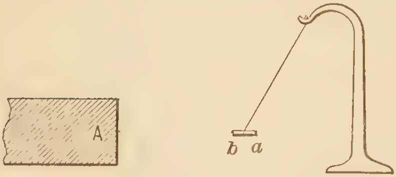

FIG. 44.—Magnetic Needle used to explore Magnetic Field around a Magnet.

It must be remembered that in all cases of attraction or repulsion between two bodies *the force exerted is mutual, and either body will be moved if not too firmly fixed.* This is true whatever be the cause of the force, as for instance, electrification, magnetism, gravity, muscular force, or any other cause. The fact that the action is mutual may be proved by placing a bit of iron on a cork floating in water and presenting a small magnet to it. The iron will be attracted by the magnet and the cork will be moved through the water by the force of the attraction. Now if the magnet is placed upon the cork and the iron is brought near it, the attraction between the magnet and the iron will again move the cork. Finally, if the iron and the magnet are placed on separate corks, the corks will move toward each other. This shows that the *force is mutual,* and it is also possible to show that the *pull on the iron is always equal to the pull on the magnet.*

**85. Lines of Magnetic Force.** — A convenient way of looking upon a magnetic field is to consider it a space which is more or less filled with lines of magnetic force. The strength of field may be represented by the number of **Lines of Force** to the square centimeter (metric measure). Then, if the strength of the field be such, for instance, that a unit pole when placed in it experiences a force of ten dynes, or units of force, we may consider the field as having ten lines of force per square centimeter. These lines of force no more actually exist than do definite stream lines, or lines of flow, exist in water which is flowing around in a tub, but the idea based on this assumed existence is a very useful and practical one. The directions of the lines of force are traced out by the iron filings as shown in Figure 39, or the path of travel of the supposed free magnet pole shown in Figure 42.

**86. Position which a Magnet tends to take in a Magnetic Field.** — From what we have learned from the mutual action of magnets, we can now see that when a magnet is placed in a magnetic field it apparently tends to set itself in such a direction that its own lines of force, where they are within its body, are parallel with the lines of force of the external field. The effect is exactly as *though lines of force tend to turn themselves so as to be parallel with each other and in the same direction.*

**87. Unit Magnetic Field.** — The theoretical method of measuring the strength of a magnetic field is by determining the force which it exerts upon a unit magnet pole. *A unit field is one which pushes upon a unit pole with a force of one unit called a dyne.* The force exerted on a magnet pole in a magnetic field depends upon the strength of the pole and the number of lines of force for every square centimeter of the field.

A *uniform field* is one which pushes upon a pole equally at all points. A *unit field* is conceived to have one line of force for each square centimeter, but it must be remembered that this arrangement is a purely hypothetical and theoretical conception.

**88. Magnetic Density and Flux.** — The magnetic density in any magnet or magnetic field is the number of lines of force passing through each square centimeter or square inch of cross section. When a magnetic field is not uniform, the density varies at different points, but in a uniform field the density is the same everywhere. This use of the term "density" is not quite like that to which we are ordinarily accustomed, but the meaning need not be misunderstood on that account, and the phrase **Magnetic Density** is a very satisfactory one.

The **Magnetism** or **Magnetic Flux** is the total number of lines of force passing through the magnet or the part of a field considered. For instance, in any particular magnet, the magnetic density in the magnet is the number of lines of force passing through each square centimeter of its cross section, while the flux in the magnet is the total number of lines passing through its entire cross section.

**89. Magnetomotive Force.** — There is evidently some **Magnetic Pressure** or *difference of magnetic level* between the two poles of a magnet, which tends to set up the lines of force between the two points. This is called **Difference of Magnetic Potential** or **Magnetomotive Force**, or better, **Magnetic Pressure**. An analogy is seen in the electrical potential which is explained in Chapter III. The stronger a magnet is, the stronger is the magnetic pressure between its poles, and the greater is the work required to push an independent north pole of given strength from the south to the north pole of the magnet. The difference of magnetic potential or the magnetomotive force between the poles of the magnet, is measured by the work required to push a *unit north pole* from the south to the north end of the magnet, — just as a mechanical potential or "head" may be measured by the work required in pushing against it.

**90. Terrestrial Magnetism.**[1] — In Article 70 it is stated that the north pole of a magnetic needle tends to point toward the north and also dips down somewhat towards the earth if permitted to do so. This indicates that the earth itself acts like a great magnet having its *negative* magnetic pole somewhere near the region of the geographical north pole. The earth's magnetic poles are probably of large surface and irregular, just as is often relatively the case in an iron magnet, and these are not exactly at the geographical poles. And so a magnetic needle will not point exactly north and south. This difference from a true north and south position is called the **Declination** of the magnetic needle, and it varies from place to place. The amount the needle dips from the horizontal is called the **Inclination**, and it is zero near the magnetic equator and ninety degrees directly over the earth's magnetic pole. The strength of the earth's magnetic field at any place is called its **Intensity**.

Each of these "elements" of the earth's magnetism varies from place to place on the earth's surface, and in addition to that varies more or less regularly from year to year, as though the earth's magnetic strength varied and the positions of its poles moved. The gradual change of the magnetic declination as time goes on changes the compass "bearings" which determine property lines in land surveying, and surveyors must carefully keep this in mind when they undertake to seek out division lines which are described in old deeds by their "bearings."

Various local disturbances may cause local variations of the compass, so that it does not point in the proper direction. Wherever iron-bearing rocks and sands are plentiful, these local variations are likely to occur; and what are called magnetic storms also cause temporary disturbances of compasses, but the effects of these usually pass away after a few days. The cause of magnetic storms is unknown, though it seems to be connected in some way with great disturbances in the solar system.

It is interesting to know that Columbus made the discovery that the magnetic declination differed at different places, when on his first voyage to America.[2] Before that time it had been supposed that the compass needle everywhere pointed to the same spot, though it was known to deviate from the true north. The discovery that the declination of the needle was variable caused great excitement and fear amongst Columbus's crew.

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[1] Also see Article 71.

[2] Article 71.

The reason that the earth is a great magnet we do not know, but its magnetic effects have been studied and its magnetic strength and the locations of its poles have been determined. Magnetic maps have also been made which show the usual declination and inclination of the magnetic needle at the different points on the earth's surface. Such maps may be used for correcting the declinations of a compass where local variations do not occur.

## QUESTIONS

1. Can you tell what magnetism is?
2. Why is magnetism supposed to be molecular in nature?
3. What is Coulomb's theory of magnetism?
4. What is Ampère's theory of magnetism?
5. When did Weber advance his theory of magnetism?
6. What is Weber's theory of magnetism?
7. What is a unit magnet pole?
8. What is the law of attraction between two magnet poles?
9. Suppose two long magnets with their poles concentrated into points, of 20 units strength each, which have their unlike poles 2 centimeters apart, what force is exerted between their two poles? *Ans.* 100 dynes.
10. Suppose two poles as in Question 9, but separated 1 centimetre, one of them being of one unit strength. If the force between them is 10 dynes, what is the strength of the second pole? *Ans.* 10 units.
11. Suppose two poles of the same strength as in Question 9. If the force exerted between the poles is 25 dynes, how far are they apart? *Ans.* 4 cm.
12. Can a magnet pole be confined to a point?
13. What is a magnetic field?
14. What is strength of field?
15. What would be the general form of the path of a free north pole if, after being placed near the north pole of a magnet, it were allowed to move?
16. Describe a number of ways by which the extent and direction of a field of force may be determined.
17. If a magnet pole is brought near a piece of iron, will the pole exert a pull on the iron? Will the iron exert a pull on the pole? Will the two pulls be equal?
18. Describe an experiment that will show that the force of attraction or repulsion between two bodies is mutual.
19. What are lines of force?

20. If a portion of a field is of 10 units strength, how can you represent it?

21. How many lines of force per square centimeter cross section are there conceived to exist in a field of 25 units strength?

22. What is the general form of the lines of force about a bar magnet?

23. If a magnet is suspended in a magnetic field, how will it tend to place itself?

24. What is a unit field?

25. How many lines of force per square centimeter cross section are there in a field of unit strength?

26. What is a uniform field?

27. If a pole of 10 units strength is placed in a field of 5 units strength, with what force will it be acted upon? *Ans.* 50 dynes.

28. If a pole of 5 units strength be acted upon by a force of 20 dynes, how strong is the field? *Ans.* 4 units.

29. If a field having 10 lines of force per square centimeter cross section acts upon a pole with a force of 2 dynes, how strong is the pole? *Ans.* $\frac{1}{5}$ unit.

30. What is magnetic density?

31. What is magnetic flux?

32. Is the magnetic density the same at all points in the field set up by a bar magnet?

33. What is magnetomotive force, or magnetic pressure?

34. Compare magnetic pressure with electric pressure.

35. When is there a unit magnetic pressure between two points?

36. Must work be done to move a north pole from the south to the north pole of a magnet?

37. Will work be done by a south pole when it moves from the south pole to the north pole of a magnet?

38. If a north pole is moved from between two points in a field against the lines of force, will the work done upon it be equal to that which the pole will do when it moves with the lines of force between the same two points?

39. How much more work will be required to move a north pole between two points if the difference of pressure is increased to double its original value?

40. If a very short magnet is placed in a magnetic field, will it tend to move bodily along the lines of force? Why not?

41. To what may the magnetic condition of the earth be compared?

42. Which is the positive magnetic pole of the earth?

43. What is magnetic declination?

44. What is magnetic inclination?

45. What is the strength of the earth's magnetic field at any point called?

46. Are declination, inclination, and intensity constant at all points of the earth's surface?

47. What variation of the earth's magnetic elements affects survey bearings?

48. Tell what you can about "local variations" and "magnetic storms."

# CHAPTER VII

## ELECTRIC CIRCUITS AND THE FLOW OF ELECTRICITY: OHM'S LAW

**91. Conductivity.** — We know by experience that the amount of energy required to propel water through a pipe depends upon the size of the pipe and its construction. Also, in two pipes of the same size, if one has a rough inner surface and the other a smooth one, we know that the former is the poorer conductor of the water. Although electricity is not a fluid, the analogy between its flow and that of water is in many ways close. The flow of electricity is also known by experience to be dependent upon the dimensions of the conductor and the material from which it is made. The electricity may be considered to flow through the entire cross section of the conductor, so that any resisting action is uniform throughout the material instead of being a "skin" or friction effect, as in the case of water flowing in a pipe. The relative powers of different materials for conducting electricity are called their **Conductivities.**

A table is given in Article 7 which shows the comparative order of the conducting powers of various materials. It is seen that the metals stand at the head of the list, and their conducting power is so much better than that of other materials that we ordinarily speak of them alone as the conductors of electricity or **Electrical Conductors.** Amongst the pure metals themselves there is considerable difference in conducting power, while mixing impurities in metals or mixing them together generally decreases their conducting power. The following table gives a number of the better known metals and common alloys in the approximate order of their conducting powers. The figures at the right hand of the names of the metals show the average relative conducting powers of pure metals and of alloys of fixed composition, in percentages of the conducting power of pure silver. Pure silver and pure copper vie with each other for place as the best conductor known, and no other metals approach them very closely. Aluminum is so very light in weight that pure aluminum conductors have even less resistance than copper conductors of equal length and weight; but the relative conducting powers or conductivities which are presented in the table refer to conductors of equal lengths and cross sections.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Silver | 100 | Aluminum | 55 | Wrought Iron | 16 | Lead | 8 |
| Copper | 100 | Zinc | 28 | Nickel | 12 | Cast Iron | 3 |
| Gold | 75 | Platinum | 17 | Tin | 12 | Mercury | 1.6 |

| | |
|---|---|
| Platinum Silver made of 2 parts Platinum and 1 part Silver | 6.4 |
| German Silver made of 5½ parts Copper, 2 parts Zinc, 2½ parts Nickel | 3.5 |
| German Silver made of 6 parts Copper, 2½ parts Zinc, 1½ parts Nickel | 5. |
| German Silver made of 5 parts Copper, 3½ parts Zinc, 1½ parts Nickel | 7.5 |

The quality of a metal and the way in which it has been handled in the course of manufacture affect the conducting power to a considerable degree. Pure copper that comes from the ore of the Lake Superior copper mines or the Montana mines appears, as a rule, to have a little higher conductivity than that coming from the Arizona mines. Annealed metals (that is, metals which have been softened and toughened by properly cooling from a high temperature) generally have a slightly greater conductivity than hardened metals, and wrought metals than cast metals.

**92. Ohm's Law.** — When water is forced through a pipe under pressure from a pump or other source of pressure, the stream of water which flows is proportional to the pressure divided by the frictional resistance which the pipe presents to the flow of the water. In the same way, when a current of electricity flows through a wire under the pressure from a battery or other source of electricity, *the current which flows in the circuit is equal to the pressure divided by the resistance of the circuit.* This relation between electric current, pressure, and resistance is called **Ohm's Law**, after the name of the German scientist who first (in 1827) formally announced it. The relation representing Ohm's Law is often written

$$C = \frac{E}{R},$$

where $C$, $E$, and $R$ stand for current, pressure, and resistance. This is a very good form in which to commit the relation to memory. The expression as written may be read $C$ equals $E$ divided by $R$.

From the relation as written above it is evident, also, that $E$ equals $C$ times $R$, and $R$ equals $E$ divided by $C$. Consequently if any two out of the three fundamental electrical quantities which exist in a circuit are given, the third can at once be calculated. Thus, if a 16 candle power incandescent lamp is known to take $\frac{1}{2}$ an ampere when connected to a circuit which furnishes current at a pressure of 110 volts, the resistance of the lamp when in operation may be calculated at once to be 110 divided by $\frac{1}{2}$, which gives the resistance as 220 ohms.

**93. The Ohm.** — **Ohm** is the name of the unit in which electrical resistance is measured, as pound is the name of the unit in which weight is measured. The word "ohm" is taken from the name of the German scientist, Dr. Ohm, who first set forth the law of electric flow as told above. Ampere (from the name of a great French scientist) is the name of the unit in which electric current is measured, as has already been explained in Article 22; and volt (from the name of a great Italian scientist) is the name of the unit in which electric pressure is measured, as has been explained in Article 23.

**94. Effect of Internal Resistance.** — In the example given above, we have assumed that the source of electricity has sufficient capacity to keep up the full pressure at the lamp terminals when current is flowing through the lamp. Sometimes this is not the case on account of the resistance to be found in the source itself, or the **Internal Resistance** of the source. A similar condition is frequently met when a pump is attached to a large hose. When the hose nozzle is partly closed, the pump will give a large pressure; but when the nozzle is opened, the pressure falls because the pump does not have sufficient capacity to keep up the supply.

When it is desired to determine the current that will flow through a circuit due to a pressure from a source of current that has an appreciable internal resistance, it is necessary to add up the resistances of all parts of the circuit before making the calculation. For instance, if two cells of battery, each giving a pressure of 1.1 volts, and each having an internal resistance of 3 ohms, are connected in series with an external circuit of 2.8 ohms resistance, then the total resistance in the circuit is 3 plus 3 plus 2.8, or 8.8, and the pressure which acts to cause current to flow through the circuit is 2.2 volts. The current flowing under these circumstances is $\frac{1}{4}$ ampere $\left(C=\frac{E}{R}, \text{ or } \frac{1}{4}=\frac{2.2}{8.8}\right)$.

### PROBLEMS

*A.* If a wire of 10 ohms resistance has a pressure of 20 volts impressed upon its terminals, what current will flow? *Ans.* 2 amperes.

*B.* What is the hot resistance of a lamp filament which uses .5 of an ampere at 100 volts? *Ans.* 200 ohms.

*C.* If a battery cell sets up at its terminals a pressure of 2 volts when on open circuit, what is its internal resistance, if the pressure, measured between the terminals, falls to $1\frac{1}{2}$ volts when 2 amperes are flowing? (Aid: $\frac{1}{2}$ volt is used in forcing the current through the cell.) *Ans.* $\frac{1}{4}$ ohms.

*D.* A lamp filament has a hot resistance of 6 ohms, and requires 1 ampere to bring it to proper incandescence. How many battery cells in series, having an open circuit pressure of 2 volts and an internal resistance of $\frac{1}{2}$ ohm each, will be required for operating the lamp? *Ans.* 4 cells.

*E.* How much pressure is generated by a battery which has an internal resistance of 8 ohms, if when it is short-circuited by a wire of negligible resistance a current of 2 amperes flows? *Ans.* 16 volts.

*F.* If the cells of Example *E* are in series and generate 2 volts each, what resistance has each cell? *Ans.* 1 ohm.

*G.* A certain piece of wire has an "insulation resistance" measured through the insulating covering between the conductor and the ground of 500,000 ohms; how much pressure would cause a current of one thousandth of an ampere to leak from it? *Ans.* 500 volts.

*H.* If a battery of five gravity cells, each of which gives a pressure of 1.08 volts, and has an internal resistance of 4 ohms, is connected in series with an external resistance of 7 ohms, what current flows through the circuit? *Ans.* $\frac{2}{10}$ amperes.

*I.* If two cells which respectively give pressures of 1.8 volts and 1.08 volts are connected to a circuit in opposition (that is, with their poles connected so that they tend to send currents in opposite directions), and a current of .4 amperes flows, how much current will flow if the cells are connected to the same circuit properly in series? *Ans.* 1.6 amperes.

**95. The Standard of Resistance.** — The resistance to the flow of water through a pipe, as said before, is a surface or "skin" friction effect, and depends upon the velocity with which the water flows, the number and form of bends in the pipe, the form of its cross section, and its length. The true electrical resistance of a conductor is quite different from this, since it simply depends upon the nature of the metal from which the conductor is made, the area of its cross section, its length, and its temperature.

*The greater the cross section of a conductor the greater is its electrical conducting power, and therefore the less is its resistance; and the longer the wire the less is its conducting power, and therefore the greater is its resistance.* The cross sections of ordinary cylindrical wires are proportional to the squares of their diameters, and consequently the conducting powers of such wires of equal length are directly proportional to the squares of their diameters. This makes the resistance of similar wires vary inversely as the squares of their diameters. For instance, if a certain copper wire has a resistance of one ohm, the resistance of a copper wire of the same length but of twice the diameter is only one-fourth of an ohm, since the square of two is four.

The adopted definition of the value of the ohm is based upon this property of *electrical resistance*, which depends simply upon the nature of the metal conductor, its temperature, its length, and the inverse of its cross section. The approved definitions of all the electrical units were adopted at the Electrical Congress held in Chicago in August, 1893. The definition of the unit of resistance makes *one ohm equal to the resistance of a column of pure mercury which is 106.3 centimeters long, which has a uniform cross section, and which contains 14.4521 grammes of mercury; the temperature being that of melting ice.* This gives to the column a uniform cross section of one square millimeter (metric system). The ohm as thus defined is called the **International Ohm**, to distinguish it from units based on definitions adopted at previous electrical congresses, and which differ slightly from the international ohm and from one another, exactly as different kinds of quart measures differ from one another, as is told in books on arithmetic. It is generally believed that the definitions given by the Chicago Electrical Congress will be universally accepted and will never be changed. The units by which electricity is measured will then be the same in all countries. This is true of no other units which are used in common measurements.

Since a column of mercury is an inconvenient device to handle, standard resistances made of mercury are not used in ordinary measurements of electrical resistance, but coils of German silver wire, or other wires of high resistance, are used. These coils are carefully adjusted in resistance to a desirable number of ohms, and they can then be used in the measurement of the resistance of any conductor by methods which will be explained on later pages. Mercury resistances are used only in well-equipped scientific laboratories to determine the real resistances of the common wire **Resistance Coils.**

**96. The Standard of Current.** — Before the Chicago Electrical Congress was held, the fundamental definition of the ampere had usually been based upon the electromagnetic effects of currents; but at that Congress a definition was adopted which is based on the electrochemical effects of currents, which are explained in Chapter V. The **International Ampere** as thus defined is the steady current which deposits silver at the rate of .001118 grammes per second from a solution of silver nitrate in water, the solution being of a given fixed strength to ensure regular action.

Measurements of electrical currents in practical tests are more frequently made by means of instruments depending upon the magnetic effects of the currents than according to the means indicated in the definition of the ampere. Methods of measurement based on the electrochemical effects of currents are very valuable for determining whether the indications of electromagnetic instruments are correct.

**97. The Standard of Pressure.** — In order that the fixed relation represented by Ohm's Law $\left(\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}\right)$ shall hold with these definitions, the **International Volt** as defined by the Chicago Congress is the pressure which causes a current of one ampere to flow through a resistance of one ohm.

**98. Effect of Temperature on the Resistance of Materials.** — Reference has already been made to the effect of temperature on the resistance of metals. The resistance of most metals increases as the temperature rises, but in the case of a few alloys the resistance falls very slightly as the temperature increases. The resistance of carbon falls quite rapidly as the temperature rises, and this fall is sufficiently great to reduce the working resistance, or **Hot Resistance**, of an incandescent lamp filament to only about one-half the resistance which it has when at the usual atmospheric temperature. The resistance of liquids and of most insulating materials, as far as they are measurable, also decreases as the temperature rises. This decrease is so marked in some insulating materials (such as glass, for instance) that they actually become conductors when they are heated red-hot or when they are melted. The operation of the new "Nernst lamps" depends upon this characteristic.

The resistance of most pure metals seems to change at approximately the same rate; namely, about .4 of 1 per cent per degree of the centigrade thermometer scale, or .22 of 1 per cent per degree of the Fahrenheit thermometer scale. (One degree of the centigrade scale is equal to $\frac{9}{5}$ of a degree of the Fahrenheit scale.) This is a fairly accurate value of the **Temperature Coefficient** of ordinary copper. A change of .4 of 1 per cent per centigrade degree means a change of 1 per cent in resistance up or down for every $2\frac{1}{2}$ degrees centigrade when the temperature varies up or down. This is also nearly equivalent to 1 per cent for every 4.5 degrees of the Fahrenheit or common thermometer scale.

The temperature coefficient of alloys depends very much upon the composition of the mixture. In general, German silver may be taken to have a temperature coefficient about one-tenth as great as that of copper. The temperature coefficients of the alloys, whose comparative conductivities are given in the first part of this chapter, are compared below with that of copper: —

| | Cent. | Fahr. |
|---|---|---|
| Copper | .40 | .22 |
| Platinum Silver | .031 | .017 |
| German Silver[1] | .033 | .018 |
| German Silver[1] | .036 | .020 |
| German Silver[1] | .040 | .022 |

The two columns of figures in this table show the approximate temperature coefficients of the metals expressed as the percentage changes of resistance per degree centigrade and Fahrenheit.

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[1] Article 91.

## QUESTIONS

1. Compare the conductivity of an electrical conductor to the conductivity of a water pipe.

2. What effect has the alloying of metals upon their conductivity?

3. What are the relative conductivities of copper, wrought iron, zinc, mercury, and German silver compared with silver?

4. How does annealing affect the conductivity of metals?

5. What is Ohm's Law?

6. When was Ohm's Law advanced?

7. Compare the relations shown in Ohm's Law to those of water flowing through pipes.

8. What is an ohm?

9. After whom were the ohm, ampere, and volt named?

10. If a battery is connected to an electric lamp, what effect upon the pressure supplied to the lamp have the connecting wires and the internal resistance of the battery itself?

11. What elements determine the resistance of a wire?

12. What effect has the cross section upon the resistance of a wire?

13. What effect has length upon the resistance of a wire?

14. Why are the resistances of cylindrical wires of like metals inversely proportional to the squares of their diameters?

15. What effect has temperature upon the resistance of most metals?

16. Define the international ohm.

17. When and where was the international ohm adopted?

18. How are standards of resistance made?

19. Define the international ampere.

20. On what principle do current measuring instruments usually depend?

21. Define the international volt.

22. What is the rough relation between the hot and cold resistances of a carbon lamp filament?

23. What effect, ordinarily, has heat upon the resistance of liquids and insulators?

24. About how much does the resistance of copper increase for each degree centigrade rise in temperature?

25. About how many degrees Fahrenheit change in temperature will change the resistance of copper by one per cent?

26. What is a temperature coefficient?

27. Do pure metals have the same or different temperature coefficients?

28. About what is the temperature coefficient of German silver compared with copper?

**99. The Circular Mil.** — In the practical measurement of wires it is usual to use feet in measuring the length and **Circular Mils** in measuring the cross section. The length of one **thousandth** of an inch is called a **Mil**, and *a round wire one mil in diameter is said to have a cross section of* **one circular mil.** The cross sections, or areas, of wires are measured in this unit; and it is a very convenient unit for this reason: the areas of circles are proportional to the squares of their diameters — consequently, if the area of a wire one mil in diameter is called a circular mil, all other round wires have an area or cross section which, in circular mils, is numerically equal to the squares of their diameters. A circle one inch in diameter is one thousand mils in diameter, and there are therefore one million circular mils in its area. As a square inch has an area $\frac{4}{\pi}$ times the area of such a circle, there must be $\frac{4}{\pi} \times 1{,}000{,}000$ (1,273,000) circular mils in a square inch. The symbol $\pi$ (Greek letter pi) is used to represent a constant value of 3.1416, which, in inches, is equal to the length of the circumference of a circle which is one inch in diameter.

**100. Specific Resistance.** — In order to find the resistance of a wire by calculation, it is necessary to know the resistance of a piece having a unit length and cross section, that is, the resistance of a wire one foot long which has a cross section of one circular mil. This may be called the **Specific Resistance** of the material or the resistance of a **Mil Foot.** The resistance of a mil foot of good commercial copper is very nearly 10.5 ohms at a temperature of 75° F. In scientific writings, specific resistance is usually given on the basis of one centimeter, as the unit of length, and one square centimeter as the unit of cross section, instead of on the basis of the mil foot which is commonly used in practice.

**101. Determination of the Resistance of a Wire.** — As has just been said,[1] the resistance of a wire or other piece of any particular metal depends directly upon its length and inversely upon its cross section. So, *if the resistance of a mil foot of the wire* (given in ohms) *is multiplied by the total length in feet and divided by its cross section in circular mils, the result will be the resistance of the whole wire in ohms.*

This may be expressed, for convenience, in this way,

$$R = X \frac{L}{\text{c.m.}},$$

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[1] Article 95.

where $R$ is the resistance in ohms, $X$ the resistance of a mil foot (which is 10.5 ohms for copper at a temperature of 75° F.), $L$ the length in feet, and c.m. the circular mils in the cross section.

Now, suppose we wish to find the resistance of a copper wire 1000 feet long and 50,000 c.m. in cross section, the following expression will result from the above reasoning: —

$$R = 10.5 \frac{1000}{50000} = .21,$$

and the resistance of the given wire is .21 of an ohm.

The specific resistance of conductors varies greatly, as will be seen by referring to the table in Article 91, where the relative conductivities of various metals are given. The specific resistance of any of the materials given in the table may be found by comparing with that of copper. For instance, if it is desired to find the specific resistance of lead in mil feet, we would divide 100 by 8, which equals 12.5, and multiply this by 10.5 (the resistance of a mil foot of copper), which shows that the value sought is 131.25 ohms.

## PROBLEMS

*A.* What is the resistance at ordinary temperature of a copper wire 2500 ft. long and having a cross section of 10,500 circular mils? *Ans.* 2.5 ohms.

*B.* Suppose it is desired to have a copper wire of .5 ohms resistance and 2000 ft. long; what must be its cross section? *Ans.* 42,000 circular mils.

*C.* If it is required to transmit 10 amperes over a copper wire 1000 ft. long with 5 volts applied at its terminals, that is, 5 volts drop, what must be the cross section of the wire? (Aid: apply Ohm's Law to find the resistance required and then proceed as in Example *B.*) *Ans.* 21,000 circular mils.

*D.* What pressure is required to force a current of 50 amperes over a copper wire 1600 ft. long which has a cross section of 20,000 circular mils? *Ans.* 42 volts.

*E.* Make a table of the specific resistances of the materials represented in the table of relative conductivities in Article 91.

*F.* If two copper wires of equal length have resistances of 4 and 9 ohms, respectively, and the diameter of the first is $\frac{1}{8}$ inches, what is the diameter of the other? *Ans.* $\frac{1}{12}$ inches.

*G.* If the resistance of a coil of wire is found to be 105 ohms, and a piece of the same wire, which is 10 ft. long, has a resistance of 1.5 ohms, how many feet of wire are contained in the coil? *Ans.* 700 ft.

**102. Circuits in Series.** — When the current passes around its circuit in a single path, the path is termed a **Series Circuit**. The path may be made up of different materials which are of various dimensions, but *the resistance of the whole is the sum of the resistances of all the parts.* Thus, suppose we have a circuit like that shown in Figure 45, where *A* is a battery of large cells having a resistance of .5 of an ohm, *B* is a small incandescent lamp having a carbon filament of 5 ohms resistance, and *C* and *D* are connecting wires having resistances of .1 and .2 ohms respectively. The total resistance of the circuit is the sum of these, or .5 + 5 + .1 + .2 = 5.8 ohms.

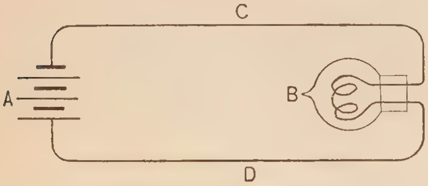

FIG. 45. — Illustration of a Series Circuit composed of a Battery, Conducting Wires, and an Incandescent Lamp.

The same condition exists when water flows through pipes. Thus, suppose in Figure 46 that *A*, *B*, and *C* are three pipes of different sizes connected in series for drawing water from a tank. Evidently the separate resistances to the flow of the water introduced by these different pipes must be added together to get the total frictional resistance from the tank to the valve. In the illustration, the tanks and pump also form parts of the circuit, and, therefore, if the total resistance of the circuit is desired, the resistances of these parts must be added to those of the pipes.

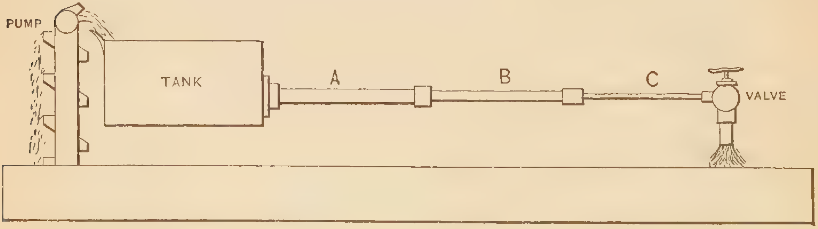

FIG. 46. — Hydraulic Analogue of Series Circuit.

## PROBLEMS

*A.* What pressure will be required to force 2 amperes through a series circuit containing a dynamo armature of ½ an ohm, conducting wires of 1½ ohms, and a lamp filament of 100 ohms resistance? *Ans.* 204 volts.

*B.* What pressure must be supplied to a line of copper wire which is 400 ft. long and has a cross section of 100,000 circular mils, in order that 200 amperes may be caused to pass through it in series with an electrolytic vat which has an apparent resistance of .03 ohms? *Ans.* 14.4 volts.

*C.* A dynamo supplies 110 volts to a copper wire circuit 400 ft. long which has a cross section of 2100 circular mils. This circuit supplies a lamp which calls for a current of 2 amperes. What is the hot resistance of the lamp filament? *Ans.* 53 ohms.

*D.* Ten 9 ampere arc lamps, each requiring 45 volts pressure, are connected in series by a copper wire having a total length of 5000 ft. and a cross section of 10,000 circular mils. The circuit also contains a dynamo armature of 5 ohms and a dynamo magnet coil of 3 ohms resistance. What is the total pressure required to keep 9 amperes flowing through the circuit? *Ans.* 569¼ volts.

**103. Circuits in Parallel.** — *If two wires are connected in parallel* (that is, so that a current divides between them, as shown in Fig. 47), *the current flowing in each is equal to the pressure between their common terminals divided by their individual resistances.* For instance, if the two wires have resistances of 4 and 6 ohms respectively, and the pressure between their terminals (the points *A* and *B*, Fig. 47) is 12 volts, the current flowing through the first wire is $\frac{12}{4} = 3$ amperes, and that through the second is $\frac{12}{6} = 2$ amperes.

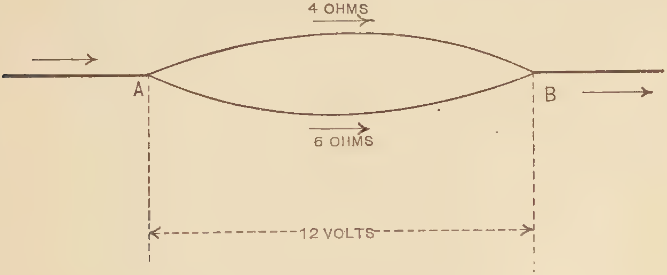

FIG. 47. — Branched or Parallel Circuit.

We have already seen that the current which flows through any resistance on account of a fixed pressure is inversely proportional to the resistance. This is shown by Ohm's Law. Accordingly, the currents flowing through the two wires of the previous example should be in the proportion of $\frac{1}{4}$ and $\frac{1}{6}$. This is true, since 3 is $\frac{1}{4}$ of 12 and 2 is $\frac{1}{6}$ of 12.

The total current flowing through the circuit containing the two wires in parallel is evidently 2 plus 3, or 5 amperes. Since the pressure causing these 5 amperes to flow through the wires is 12 volts, the resistance of the circuit between *A* and *B*, or the **Joint Resistance** of the two wires in parallel, must be $\frac{12}{5}$, or 2.4 ohms. This may be conveniently calculated directly from the conductivities, which, it will be remembered, are reciprocal or inverse to the resistances.[1] The conductivity of the first wire is therefore $\frac{1}{4}$ and that of the second is $\frac{1}{6}$.

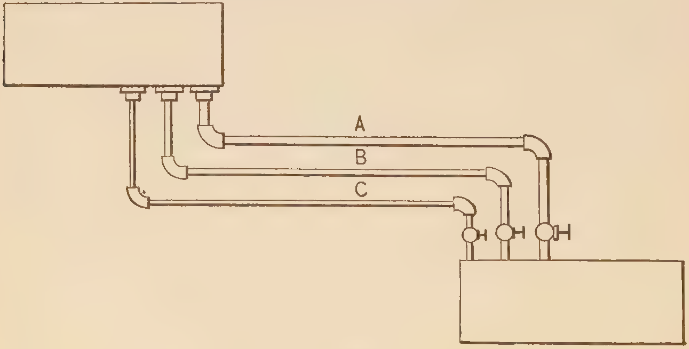

FIG. 48. — Hydraulic Analogue of Branched Circuit.

The joint capacity of two or more pipes which deliver water between two tanks is equal to the capacities of all the separate pipes added together. Thus suppose in Figure 48, *A*, *B* and *C* are three pipes connecting the two tanks. Evidently more water will flow through two pipes in a given time than through one alone, and still more will flow through three pipes; hence as pipes are added between the tanks the resistance to the flow of water is decreased, that is to say, the conductivity is increased. The capacities of the pipes for carrying water, that is their conductivities, must therefore be added together to get the total conductivity for the flow of water from the higher tank to the lower one.

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[1] Article 23.

We also say what means exactly the same thing, though it is put in different words, when we say that the reciprocals of the individual pipe resistances must be added to give the joint conductivity of all together. As this sum gives the combined conductivity of all the pipes, its reciprocal will be the combined resistance.

In the same way the joint conducting power of electric circuits which are connected in parallel, or **Divided Circuits** as they are often called, *is equal to the conducting powers of the parts added together.* The joint-conducting power or conductivity in the previous example is therefore $\frac{1}{4}$ plus $\frac{1}{6}$, or $\frac{5}{12}$. The resistance of the divided circuit is the inverse of this, which is equal to $\frac{12}{5}$, or 2.4, as previously calculated.

This shows that simply adding together the resistances of the individual parts of a circuit will not always give the total resistance of the circuit. In fact, such an addition gives the total resistance only when all the individual resistances belong to *parts of the circuit which are connected in series.*

A little consideration of what precedes will show that when two wires of equal resistance are connected in parallel, their joint resistance is *just half as great* as the resistance of either wire. If three wires of equal resistance are connected in parallel, their joint resistance is just one-third as great as the resistance of one of the conductors, and so on. If the wires of equal resistance were connected in series instead of parallel, the resistances would be two, three, and so on, *times* as great as a single wire. A simple rule for calculating the joint resistance when only two wires are connected in parallel, is to multiply together the individual resistances of the wires and divide this product by the sum of the individual resistances. This comes directly from the laws of the electric current and the resistances of divided circuits, as explained above. But it is generally simpler where there are more than two branches in parallel, to consider the conductivities when calculating the joint resistance of parallel circuits, in the way that has also been explained above.

## PROBLEMS

*A.* Suppose an electric battery is connected to an external circuit of two parallel branches, one of these having a resistance of 20 ohms, and the other a resistance of 40 ohms, what proportion of the total current flows through each branch? *Ans.* $\frac{2}{3}$ and $\frac{1}{3}$.

*B*. What is the resistance of a series circuit made up of the following resistances: 1st part, 4 ohms; 2d part, 2 ohms; 3d part, $1\frac{1}{3}$ ohms; and what would be the joint resistance if the parts were joined in parallel? *Ans.* $7\frac{1}{3}$ ohms, and $\frac{2}{3}$ ohms.

*C*. Four parallel circuits of 1, 2, 4, and 5 ohms resistance, respectively, have 20 volts impressed upon their terminals. What is the total current that flows? *Ans.* 39 amperes. How much current flows through each branch? *Ans.* 20, 10, 5, 4.

*D*. What is the joint conductivity of three parallel branches which have respectively 4, 5, and 20 ohms resistance? *Ans.* $\frac{1}{2}$. What is the joint resistance? *Ans.* 2 ohms.

*E*. What is the joint resistance of four parallel branches which have respectively 1, 4, 5, and 20 ohms resistance? *Ans.* $\frac{2}{3}$ ohms.

*F*. If the resistance of a wire is 4 ohms, what must be the resistance of another, which when put in parallel with it makes the joint resistance 3 ohms? *Ans.* 12 ohms.

*G*. The joint parallel resistance of five wires, each of the same resistance, is 5 ohms, what is the resistance of each of the wires? *Ans.* 25 ohms.

*H*. What is the joint resistance of four wires in parallel which have resistances, respectively, of $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{9}$, and $\frac{1}{10}$ of an ohm? *Ans.* $\frac{1}{25}$ ohms.

*I*. What is the joint resistance of three circuits in parallel which have respectively resistances of 1, .5 $(=\frac{1}{2})$, .2 $(=\frac{1}{5})$ ohms? *Ans.* .125 $(=\frac{1}{8})$ ohms.

*J*. If ten similar incandescent lamps, connected in parallel at an electrolier, have a joint resistance of 20 ohms, what is the resistance of each lamp? *Ans.* 200 ohms.

*K*. Three copper circuits in parallel supply a building with 300 amperes to run electric lamps. The wires composing the circuits are, respectively, of 75,000, 105,000, and 120,000 circular mils cross section and 1000 feet long. If the satisfactory operation of the lamps requires 100 volts at their terminals, how many volts must be impressed upon the wires? (Aid: Add the circular mils together and compute the joint resistance; then find the volts lost in the wires.) *Ans.* 110.5 volts.

*L*. There are four incandescent lamps of different sizes, placed in parallel upon a circuit. These have respective resistances of 100, 150, 200, and 300 ohms. What total current passes through this group of lamps, when 100 volts is applied at its terminals? *Ans.* 2.5 amperes.

*M*. A copper wire with a cross section of 105,000 circular mils, 600 ft. in length, was used for transmitting a current of 100 amperes between two buildings. The current was afterward increased to 150 amperes and a second wire added in parallel with the first of such size that the drop of pressure in the circuit was the same as before. Of what cross section was the second wire? (Aid: The total wire cross section must be increased in proportion to the increase of current.) *Ans.* 52,500.

*N*. Ten battery cells of 2 volts pressure and 1 ohm internal resistance each are connected in parallel and short circuited by a wire of negligible resistance. What is the current that flows through the short circuit wire? *Ans.* 20 amperes.

*O*. Four insulated telegraph wires have a common terminal connected to one terminal of a 20 volt battery. The other terminal of the battery is connected to the earth. If the insulating resistance of the wires from the earth are respectively 100,000, 200,000, 250,000, and 1,000,000 ohms, how many thousandths of an ampere of leakage current will flow between the wires and earth? *Ans.* .40 milliamperes.

*P.* A bare transmission line is supported by 500 glass insulators each of which has on a certain day an insulation resistance of 5,000,000 ohms. What is the insulation resistance of the line? *Ans.* 10,000 ohms.

*Q.* A certain telegraph wire, 50 miles long, has an insulation resistance to earth of 40,000 ohms. How much current (in thousandths of amperes) will leak to earth when a battery of 20, $1\frac{1}{5}$ volt battery cells are connected in series between the line and the earth? *Ans.* .6 milliamperes.

**104. Series and Parallel Circuits Combined.** — Circuits are sometimes spoken of as **Simple Circuits** when the parts are all in series, and **Branched, Compound,** or **Derived Circuits,** when the parts are in parallel. Parallel connection is sometimes called connection in **Multiple** or **Multiple Arc.**

The total resistance of a circuit made up of *parts connected in series* is equal to *the sum of the individual resistances of all the parts.*[1] The total resistance of a circuit made up of *parts connected in parallel* is equal to *the reciprocal of the total conductivity of the circuit, and the total conductivity is equal to the sum of the individual conductivities of the parts.*[2]

When part of the total circuit is made up of conductors in parallel it is necessary to first calculate the joint resistance of that part and then add that to the resistance of the remainder of the circuit which is in series with the branched portion. It is easily seen that the *joint resistance of conductors in parallel is equal to the resistance of a single conductor with which*

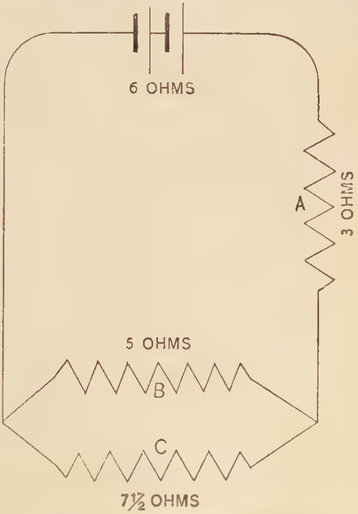

FIG. 49. — Compound Circuit.

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[1] Article 102.

[2] Article 103.

*they might be replaced without changing the total resistance of the circuit.* A circuit which contains a portion composed of two conductors in parallel is shown in Figure 49. Suppose that the resistances in ohms of the different parts are as marked, then the total resistance of the circuit is 12 ohms. If the pressure developed by each of the two cells which are represented by the usual sign, ▮|, is 1.2 volts, the current flowing through the circuit is $\frac{2.4}{12} = .2$ amperes.

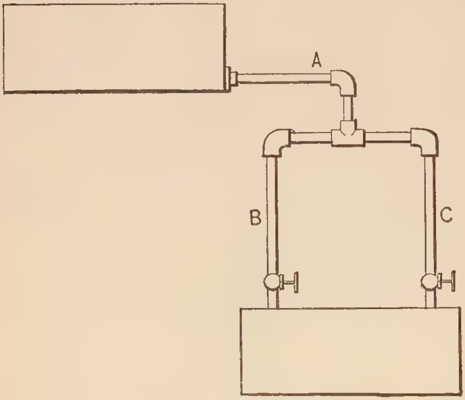

FIG. 50. – Hydraulic Analogue of the Compound Circuit illustrated in Fig. 49 (omitting the pump, which in the analogy takes the place of the electric battery).

This would be analogous to a system of water piping between two tanks as seen in Figure 50. In this case the resistance of B and C, formed by taking the reciprocal of the sum of their conductivities, must be added to the resistance of *A* to get the total pipe resistance between the tanks.

## PROBLEMS

*A.* A wire of 2 ohms resistance is connected in series with a group of three wires in parallel which are of 4, 5, and 20 ohms resistance, respectively. What is the total resistance? *Ans.* 4 ohms.

*B.* A copper wire 200 ft. long and 10,500 circular mils in cross section is in series with two parallel wires 400 ft. long. One of the latter wires has a cross section of 7000 circular mils, and the other a cross section of 14,000 circular mils. What is the resistance of the circuit? *Ans.* .4 ohms.

*C.* A group of wires in parallel, of 2 and 6 ohms resistance, respectively, is connected in series with another group of three wires in parallel, with 1, 3, and 6 ohms resistance, respectively. If the conductor by means of which the two groups are connected in series has a resistance of 1.5 ohms, what is the total resistance of the system? *Ans.* $3\frac{2}{3}$ ohms.

*D.* Four cells which give a pressure of 1.5 volts and have an internal resistance of 2 ohms, each, are connected in parallel. The cells supply current to a circuit of ½ an ohm resistance. What current flows? *Ans.* 1½ ampere.

*E.* If the battery of Example *D* is connected in two parallel sets of two cells in series, what current flows? *Ans.* 1⅕ amperes.

*F.* We have six battery cells of 2 volts pressure and 2 ohms internal resistance each. How shall they be connected to get the greatest current through a 3 ohm circuit? (*Aid: In order that the largest current may be caused to flow through a circuit by a given number of battery cells; or a given current may be caused to flow by the smallest number of cells; the cells must be grouped so that the internal resistance of the battery is as nearly as possible equal to the external resistance in the circuit. Therefore, group the cells so that the external resistance is as nearly as possible equal to 3 ohms.*) *Ans.* Two parallel sets of three cells in series.

*G.* A building has ten electric fire-alarm bells, each of 10 ohms resistance, connected in parallel. If these bells act as ordinary resistances and the connecting wires are of negligible resistance, what is the least number of 2-volt battery cells, having an internal resistance of 2 ohms, that would be required to send .2 of an ampere through each bell? (Aid: Read aid to Example *F*, and group cells so that internal and external resistances are as nearly as possible equal.) *Ans.* 8; 4 parallel sets of 2 cells in series.

*H.* The conductors to a group of 25 incandescent lamps are of .2 ohms resistance. Each lamp has a hot resistance of 200 ohms and requires .5 of an ampere for its operation. What is the total pressure required? *Ans.* 102.5 volts.

*I.* A dynamo which delivers 500 amperes at a pressure of 20 volts is to be used for supplying current to 20 electrolytic vats, each of which requires 100 amperes at a pressure of 5 volts. How shall the vats be connected up? *Ans.* 5 parallel sets of 4 vats in series.

*J.* A building contains one hundred 100 volt incandescent lamps of 200 ohms hot resistance each, connected in parallel. The copper wires from the dynamo to the building are 400 feet long (total). What size must the conducting wire be if the dynamo delivers its current at a pressure of 110 volts? (Aid: 10 volts are left for forcing the current through the wire.) *Ans.* 21,000 circular mils.

*K.* 400 incandescent lamps in parallel, of ½ amperes and 100 volts each, are to be operated by a storage battery. The battery cells have an open circuit pressure of 2 volts and an internal resistance of .0037 of an ohm each. How many cells will be required if each cell is not to discharge over 40 amperes? *Ans.* 5 parallel rows of 54 cells in series.

*L.* Suppose an electric battery of 20 volts open circuit pressure and 6⅔ ohms internal resistance is connected to two external branches which are in parallel, one of these having a resistance of 20 ohms and the other a resistance of 40 ohms; how much current flows through the battery and how much through each of the external circuits? *Ans.* 1, ⅔, and ⅓ amperes.

**105. Shunts.** — When one wire is connected in parallel with another it is often called a **Shunt**, because it switches off or **Shunts** a part of the current from the other wire. The wire to which a shunt is attached is said to be **Shunted.** Special shunts put up in boxes are frequently used to protect electrical instruments which are required for electrical measurements, their purpose being to shunt a known part of the current around the instruments when the currents are so great that the instruments might be injured if the total current passed through them.

**106. Fall of Pressure along a Circuit.** — Since Ohm's Law shows that the electrical pressure between two points in a circuit is equal to the current flowing in the circuit multiplied by the resistance of the part of the circuit between the points, we may say that the pressure along a wire falls or "drops" in proportion to the resistance passed over. Thus, suppose the terminals of a copper wire of uniform cross section and 10 feet long are connected to the poles of an electric battery furnishing a pressure of two volts. Now, since equal lengths of the uniform wire may be considered as having equal resistances and all parts of the wire carry the same current, the electrical pressure measured between the middle of the wire and one end must be equal to the pressure measured between the middle and the other end, and this must also be equal to one volt or one-half the total pressure measured between the ends of the wire. In the same way *the pressure measured across* (that is, the "drop of pressure" in) *any portion of the wire bears the same proportion to the two volts' total pressure as the length of the portion bears to the whole length of the wire.*

If one end of the wire, while still connected to the battery, is connected to the ground (by attaching to a water or gas pipe) it may be considered as being a zero pressure; then the other end of the wire is at an actual pressure of two volts. (The difference of pressure between the two ends of the wire was considered before without taking into account their actual pressures. The same thing is often done in considering the flow of water or gas through a pipe.) The middle of the wire is now at a pressure of one volt, while $2\frac{1}{2}$ feet (or one-quarter the length of the wire) from the higher end the pressure is $1\frac{1}{2}$ volts, and $7\frac{1}{2}$ feet (or three-quarters of the length of the wire) from the upper end the pressure is $\frac{1}{2}$ volt (see Fig. 51).

If the wire were not of a uniform cross section, or were composed in different parts of different metals, the resistances of equal lengths would no longer be the same. The pressures measured across the portions of the wire would no longer be directly proportional to the lengths of the portions, but would be *proportional to their resistances*, as before.

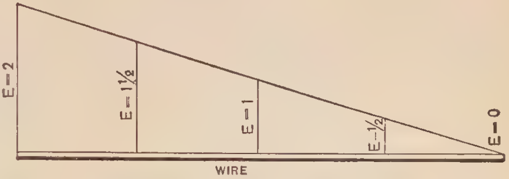

FIG. 51.—Illustration of Fall of Pressure along a Wire of Uniform Resistance.

**107. General Law for Fall of Potential in a Circuit.**—This general rule may therefore be written as a result of Ohm's Law: *the electrical pressure along a conductor through which a given current flows, falls directly as the resistance passed over.* The same rule holds in the case of gas or water flowing through a pipe. Suppose it requires 10 pounds pressure to cause 500 gallons of water to flow per minute through a certain straight pipe 200 feet long. If the pipe is cut in half, 5 pounds pressure is sufficient to pass the same amount of water through either half. If pressure gauges are attached with proper precautions to the pipe at intervals of 20 feet, each gauge will show a pressure of one pound less than the preceding one, when taken in the direction of the current. This shows that the pressure falls directly as the resistance passed over as in the case of the electric current.

## PROBLEMS

*A.* A copper wire of uniform size 100 feet long and of 10 ohms resistance is connected to the terminals of a 20 volt battery of negligible internal resistance. If the negative terminal of the battery is considered to be at zero potential, what is the potential of the wire at each successive 10 foot mark, measured from the negative terminal? *Ans.* 2, 4, 6, 8, 10, 12, etc., volts.

*B.* Three wires of 2, 6, and 8 ohms resistances are connected in series between the terminals of a battery which gives a terminal pressure of 2 volts when so connected. What is the pressure between either battery terminal and the wire joints? *Ans.* .25 or 1.75, and 1 or 1 volts.

*C.* A battery cell gives 1.5 volts on open circuit, and has an internal resistance of 3 ohms. To what will the terminal pressure of the cell fall on account of the drop of pressure in the cell itself, when a current of .1 ampere flows? *Ans.* To 1.2 volts.

*D.* Ten 40 volt, 10 ampere lamps are connected in series, with 1000 feet of copper wire between each pair of lamps. The wire has a cross section of 10,500 circular mils. If the outside terminal of the first lamp is at a pressure of 5 volts, what is the pressure at the farther terminal of each lamp? *Ans.* 55, 105, 155, etc., volts.

*E.* A magnet coil of 2 ohms resistance is supplied with current through a wire of 1 ohm resistance. The current is supplied by a battery of ten battery cells in series, each of which has an internal resistance of .2 of an ohm and gives 2 volts pressure on open circuit. What is the pressure between the terminals of the coil? (Aid: The required pressure is $\frac{2}{5}$ of 20 volts.) *Ans.* 8 volts.

*F.* It is desired to shunt the 1000 ohm coil of a galvanometer so that when it is connected into a circuit only $\frac{1}{3}$ of the current in the circuit will pass through this coil. What is the resistance of the shunt? *Ans.* 500 ohms.

*G.* If a uniform wire 20 feet long measures 1 ohm, what is the fall of pressure per foot when 1 ampere flows through it, and also when 2 amperes flow through it? *Ans.* $\frac{1}{20}$ and $\frac{1}{10}$ volts.

## QUESTIONS

29. What is a mil?

30. What is a circular mil?

31. How many circular mils are there in a round wire 50 mils in diameter?

32. What must be the diameter of a wire, in mils, in order that it may have a cross section of 400 circular mils?

33. What is a mil foot?

34. What is specific resistance?

35. What is the numerical value of the specific resistance of copper?

36. Is the specific resistance of iron greater or less than that of copper?

37. How may the resistance of a copper wire be calculated?

38. What is a series circuit?

39. Give an example of a series circuit.

40. How is the total resistance of a series circuit, made up of a number of parts, determined?

41. What are circuits in parallel?

42. What is joint resistance?

43. What are divided circuits?

44. How may the total current in a divided circuit be found if the pressure and individual resistances are known?

45. How may the joint resistance of two parallel wires be found if the individual resistances are known?

46. What is the reciprocal of the resistance of a wire?

47. Will adding the individual resistances of wires in parallel give the joint resistance?

48. What will adding the conductivities of wires in parallel give?

49. What will the reciprocal of the combined conductivity of wires in parallel give?

50. How do you know that the joint resistance of five wires in parallel, each of 1 ohm resistance, is one-fifth of an ohm?

51. What are simple circuits? Compound and divided circuits? Multiple or multiple arc circuits?

52. How can you find the resistance of a compound circuit?

53. If a wire of $\frac{1}{2}$ ohm is connected in series with two parallel wires each having a resistance of 1 ohm, what is the total resistance?

54. What are shunts?

55. How does the potential or pressure fall along a uniform wire?

56. What does the fall of pressure depend upon in a wire made up of several pieces of different sizes and different materials?

57. Give a water-pipe analogy to electric fall of potential.

# CHAPTER VIII

## ELECTRICAL ENERGY, HEATING EFFECTS OF ELECTRIC CURRENTS, AND MISCELLANEOUS EFFECTS OF ELECTRIC CURRENTS

**108. Electric Work and its Unit of Measurement.** — When one coulomb of electricity is passed through a wire under the pressure of one volt, a certain amount of work is done, exactly as another certain amount of work is done when a gallon of water is raised a foot in height by means of a pump. In the case of the water the work done is measured in **Foot Pounds.** *A foot pound means an amount of work which is done when a force equivalent to one pound's weight has caused a body to move through a distance of one foot.* If one lifts a pound of sugar or other material through a vertical distance of one foot, he has caused the movement by the exertion of a force equivalent to one pound's weight, and therefore has done one foot pound of work.

In order to determine the foot pounds of work done in pumping water, the pressure under which the water is pumped must be converted into its equivalent feet of **Head** and the quantity of water must be given in pounds. The weight of a gallon of water is about $8\frac{1}{3}$ pounds. Consequently, if one gallon of water is passed through a pipe under a pressure which is equivalent to one foot of **Head,** about $8\frac{1}{3}$ foot pounds of work are done $(1 \times 8\frac{1}{3} = 8\frac{1}{3})$.

When one coulomb of electricity is passed through a wire under a pressure of one volt, the amount of work done is called one **Joule,** after the name of Joule, a great English scientist and engineer.

**109. Power and its Unit of Measurement.** — As a general thing we do not care to pump a single gallon of water through a pipe, but we wish to pump a given *number of gallons per minute.* In this case for each gallon passed per minute through the pipe under a pressure which is equivalent to the head of one foot, about $8\frac{1}{3}$ foot pounds of work must be done every minute. Suppose it is desired to pump 120 gallons (1000 pounds) of water per minute through a pipe under a head of 33 feet, the work required to do this is 33,000 foot pounds per minute.

*The rate at which work is done*, that is, the amount done in a given time, such as a minute, is called **Power.** Mechanical power is ordinarily divided into units called **Horse Power.** *A horse power is equal to 33,000 foot-pounds of work done per minute*, so that in the last example exactly one horse power is required to move the water.

The horse-power hour is frequently used as a unit of work. It is the amount of work done by a horse power working for one hour, and is equal to 1,980,000 foot pounds (33,000 × 60 = 1,980,000).

The horse power of a waterfall is calculated in a way which is similar to the preceding examples. Suppose a stream discharges 480 gallons, or 4000 pounds of water per minute, over a fall 25 feet high, the power of the water is 100,000 foot pounds (100,000 = 25 × 4000) per minute, or a little over three horse power.

The horse power of steam engines is also calculated in a similar manner. For instance, in an engine which is supplied with steam that exerts an average pressure on the piston of 40 pounds per square inch along the whole stroke, and the piston of which has a surface of 100 square inches, the total pressure exerted by the steam on the piston is 4000 pounds. If the stroke of the engine is 1 foot, the piston moves 2 feet per revolution, and consequently the steam exerts 8000 foot pounds of work (8000 = 2 × 4000) in each revolution. If the engine runs at 250 revolutions per minute, the work done by the steam is 2,000,000 foot pounds (2,000,000 = 250 × 8000) per minute, or just a little more than 60 horse power. This is called the *indicated horse power* of the engine. Most of it is available for driving machinery, but a portion is used in overcoming the friction of the engine itself.

**110. The Watt.** — We have already explained in this chapter that when a coulomb of electricity is sent through a wire under a pressure of one volt, an amount of work is done which is called a joule; we have also explained in Article 22, that a current of one ampere is a current which conveys one coulomb per second. Consequently when a current of one ampere is passed through a wire under a pressure of one volt, the amount of work done is equal to one joule per second. This represents a certain amount of power which is called a **Watt**, after James Watt, a great English engineer, and inventor of the modern steam engine. The power represented by one watt is equal to one seven hundred and forty-sixth part of a horse power, or there are *746 watts in a horse power.* In speaking of the power of electrical machinery, it has become customary to use the electrical term "watt," and for a larger and frequently more convenient unit the **Kilowatt** is used. This is equal to 1000 watts, or about $1\frac{1}{3}$ horse power.

When a steady electric current flows through a circuit, the power used in the circuit is equal to the current multiplied by the total pressure causing the current to flow; that is, *the power in watts is equal to the current in amperes multiplied by the pressure in volts, or* $P = C \times E$. Part of this power may be used in causing electrochemical action (by charging a storage battery, for instance), or it may be used in driving machinery through the medium of an electric motor; but some of the power is always used in overcoming the resistance of the wires which convey the current. This is somewhat similar to the use of some of the indicated power of a steam engine in overcoming the friction of the engine itself.

## PROBLEMS

*A.* 2000 coulombs of electricity are passed through an electrolytic vat each second, under a pressure of 6 volts. How many joules of work are expended in an hour? *Ans.* 43,200,000.

*B.* If 3730 watts are expended in a circuit, how many horse power are being developed? *Ans.* 5.

*C.* If 10 horse power of mechanical energy were converted into electrical energy how many watts would be developed? *Ans.* 7460.

*D.* 100 horse power expended continuously for one hour will produce how many kilowatt hours (kilowatt working for one hour)? *Ans.* 74.6 kilowatt hours.

*E.* In example *A* how many horse power are being used? *Ans.* 16 (approx.).

*F.* How many foot pounds of work will be expended in a minute by a current of 373 amperes flowing under a pressure of 20 volts? *Ans.* 330,000.

*G.* A 25 horse power engine drives a dynamo. If the dynamo gives out 80 per cent of the power supplied to it, what number of kilowatts does it develop? *Ans.* 14.92.

*H.* An elevator weighing 1000 pounds is to be lifted at the rate of 198 ft. per minute. If the driving motor delivers 75 per cent of the electrical energy it receives, how many kilowatts must be supplied to the motor? *Ans.* 5.968.

*I.* A current of 25 amperes flows through a circuit under a pressure of 100 volts; what is the power? *Ans.* 2500 watts.

*J.* If 100 watts are expended in a circuit by a current of 5 amperes, what is the pressure required to drive the current through the wire? *Ans.* 20 volts.

*K.* If 100 incandescent lamps, using 100 volts each, are connected in fifty parallel sets of two lamps in series, and if they use a total of 5 kilowatts, what is the current used by each lamp? *Ans.* .5 ampere.

**111. Conservation of Energy.** — When mechanical energy is used in overcoming friction or other forms of resistance, *it is not lost, but is converted into an equivalent amount of heat which is another form of energy.* A general law may be stated thus: **Energy** (that is, the capability of doing work) *is never destroyed, but it may be transformed from one form into another.* This is called the Law of the Conservation of Energy.

When energy is transformed from one form to another, as when mechanical power is changed to electrical power or the reverse, there is always some loss of the amount of useful energy. This apparently lost energy has not been destroyed, however, but has been converted into heat. For instance, when the mechanical power conveyed by a running belt is changed by means of a dynamo of satisfactory size into electrical power, about 10 per cent of the available energy is lost. That is, the electrical energy delivered by the dynamo is about 10 per cent less than the mechanical energy which is given to the dynamo. Energy has not been destroyed by this process, but the difference has been converted into heat in overcoming the friction of the dynamo bearings, the resistance of the wire windings of the dynamo, and in other ways. A dynamo which is in operation is always found to be warmer than the surrounding air, which indicates that some of the energy delivered to the dynamo has been changed into heat that goes to warm the machine. The practical usefulness of this portion of the energy which has been converted into heat is lost, but the energy itself is not destroyed.

**112. Power used in overcoming Electrical Resistance.** — The power which is used in overcoming the electrical resistance of a wire when a current is passed through it is converted into heat which warms the wire. The heat produced is proportional to the number of watts expended in causing the electric current to flow through the resistance of the wire; and this is equal to the difference of pressure at the terminals of the wire multiplied by the current flowing in it ($P = C \times E$), provided all the power expended in that part of the circuit is used in heating the wire.

According to Ohm's Law, pressure is equal to current times resistance, or

$$E = C R.$$

Consequently $C$ times $E$ is equal to $C$ times $C\ R$, or $C$ squared times R. Hence *the power required to overcome the resistance of a wire is equal to the square of the current multiplied by the resistance* or

$$P = CE = C^2R.$$

By again substituting according to Ohm's Law, it may be shown that the power lost in a wire is also equal to the pressure squared divided by the resistance, or

$$P = CE = \frac{E^2R}{R^2} = \frac{E^2}{R}$$

Power is in every case given in watts, provided the current is given in amperes and the resistance is given in ohms or the pressure in volts.

Since the portion of the available electrical power of a circuit which is lost in heating the conductors is equal to the current squared times the resistance of the conductors, it is often spoken of as the *C squared R loss.*

### PROBLEMS

*A.* A current of 50 amperes is passed through a resistance of 5 ohms. How many watts are expended in heating the wire? *Ans.* 12,500.

*B.* An incandescent lamp requires .6 of an ampere of current. The resistance of its filament is 200 ohms. How many watts are required for it? *Ans.* 72.

*C.* A wire of 20 ohms resistance first has a current of 6 amperes and then a current of 18 amperes passing through it. How many times greater is the heating effect of the latter current than that of the former? *Ans.* 9.

*D.* A copper wire 10,500 circular mils in cross section and 1050 feet long carries a current of 50 amperes. What must be the cross section of an aluminum wire of the same length to carry the same current with the same loss? *Ans.* 19,090 cir. mils.

*E.* It is found that 2 kilowatts are wasted upon a copper wire 1000 feet long when 20 volts are impressed upon its terminals. How large is the wire? (First, find resistance of the wire by Ohm's Law and then the cross section.) *Ans.* 52,500 cir. mils.

*F.* Current is supplied to a group of 50 incandescent lamps, connected in parallel, each having a resistance of 180 ohms, through a wire of .4 of an ohm resistance. What per cent of the total power is lost in the wire? (Aid: Find resistance of lamps; the loss will be proportional to resistance.) *Ans.* 10 per cent.

*G.* If 10 kilowatts are transmitted over a wire of certain resistance and at a pressure of 100 volts, what pressure will be required to transmit the same power at $\frac{1}{4}$ as much loss in the wire? (Aid: The loss in a wire varies inversely as the square of the pressure.) *Ans.* 200 volts.

*H.* If it requires a wire of 500,000 circular mils cross section to transmit 100 kilowatts at a pressure of 100 volts over a wire 15,000 ft. long at a required loss, how large a wire will be required to transmit the same power at 1000 volts pressure with the same expenditure of energy? (Aid: The cross sections of the wires vary inversely as the squares of the pressures.) *Ans.* 5000 cir. mils.

*I.* How far can 100 kilowatts be transmitted over a copper wire having a resistance of .005 of an ohm per 100 ft. with a loss of 10 kilowatts in the wire, at 100, 500, 1000, and 10,000 volts, respectively? (Aid: Find the current and then the loss per 100 ft. Divide the loss in watts per 100 ft. into 10,000 (*i.e.* 10 kilowatts), and the result will be the number of hundreds of feet.) *Ans.* 200, 5000, 20,000, and 2,000,000 ft.

*J.* Two Leclanché cells are connected in series in opposition to a third one. The pressure of each cell is 1.5 volts, and its resistance 5 ohms. If the free terminals of the three cells are connected together by a wire of negligible resistance, how much power is being expended in the resistance of the cells? (Aid: Take the difference of the two opposing pressures.) *Ans.* .15 watts.

*K.* If ten 1.05 volt Daniell cells are connected in series in a circuit with seven 1.5 volt Leclanché cells connected in opposition to them, how much work will be done in the circuit? *Ans.* None.

*L.* A Leclanché cell has at a certain instant an internal resistance of 8 ohms, a total pressure of 1.7 volts, and a counter pressure, due to polarization, of .5 of a volt. The cell is connected to an external circuit of 8 ohms resistance. What power is it giving to the external circuit? *Ans.* .045 watts.

**113. The Calorie and its Relation to the Joule.** — It is possible to measure an electric current by the heat produced when it is passed through a known resistance. This is usually done in an instrument called a **Calorimeter** (Fig. 52), which is a vessel containing water or some other liquid in which the resistance is immersed. The vessel usually is double walled or arranged in some other way so that it will not lose heat rapidly by *radiation* into the air. A thermometer is immersed in the liquid to determine its rise of temperature due to the heat given it from the wire. The amount of heat which is required to raise the temperature of a gramme of water one degree of the centigrade scale is called a **Calorie.** The number of calories given by the wire to the water in the calorimeter is determined from the amount of water and its rise in temperature, proper corrections being made for the effect of the vessel.

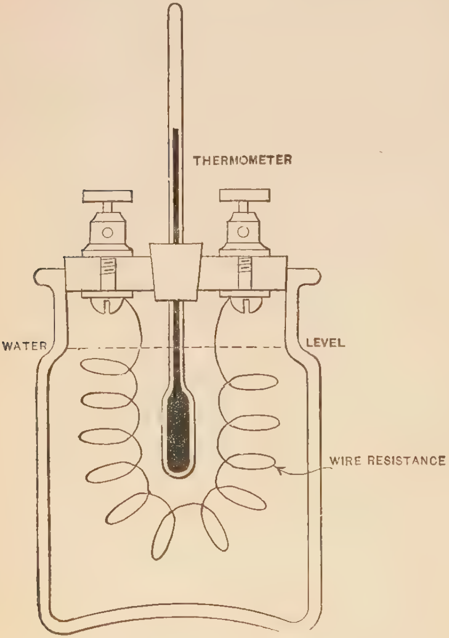

FIG. 52. — Simple Form of Electric Calorimeter.

The experiments of Joule, of Rowland (an American scientist), and of others have shown that the work represented by one joule is equivalent to the heat represented by practically .24 of a calorie. Consequently, *the total number of calories of heat produced in one second by the current passing through the wire in a calorimeter is equal to .24* $C^2R$. The total heat produced in any time is also equal to .24 $C^2R$ multiplied by the number of seconds in the time. This may be written in the form

$$H = .24 C^2RT.$$

This experimentally determined fact, or law of nature, is sometimes called Joule's Law.

By determining the total heat produced in the calorimeter in a fixed time, when the current is passed through a known resistance, the value of the current may be determined. The square of the current is equal to the calories divided by .24 times the resistance multiplied by the time in seconds.

It may be seen from what precedes that *one ampere flowing through a resistance of one ohm expends continuously a power of one watt,* which is equivalent to the expenditure of one joule of work every second, *and that it produces .24 calories of heat every second.*

## PROBLEMS

*A.* How much heat will be developed in a wire having a resistance of .5 ohms if a current of 10 amperes flows through it for an hour? *Ans.* 43,200 calories.

*B.* If a pound of carbon will give out 228,000 calories in its combustion, how many joules of work can it do in heating? $\left(\text{Aid: Joule} = \frac{\text{calorie}}{.24}.\right)$ *Ans.* 950,000.

*C.* If a battery of 9 Daniell cells of 1.2 volts pressure and 2 ohms internal resistance each, be connected up in three sets in parallel of three cells in series, how much heat will they, in one hour, develop in a wire of 2 ohms resistance? (Aid: Find the total pressure and resistance of the battery and the current that will flow; afterward apply Joule's Law.) *Ans.* 1400 calories (approx.).

*D.* Can the cells in Example *C* be arranged to give heat to the wire at a higher rate? *Ans.* No.

*E.* How many joules of work will be done in raising the temperature of 600 grammes of water 24 degrees centigrade? *Ans.* 60,000.

*F.* A battery is connected to a wire coiled up in a calorimeter which contains 600 grammes of water. The temperature of the water rises 10° C. in 10 minutes. If $\frac{1}{6}$ of the heat is lost by radiation, how much power is supplied to the coil by the battery? (Aid: Watts = joules expended per second.) *Ans.* 50 watts.

*G.* A current was passed through a coil of wire of 1 ohm resistance in a calorimeter containing 400 grammes of water. The water rose 8 centigrade degrees in temperature in 400 seconds. If $\frac{1}{5}$ of the heat was lost by radiation, how much current was flowing? (Aid: Find the total calories; then solve for $C$ in $H = .24\ C^2RT$.) *Ans.* 6.4 amperes.

*H.* A current of 10 amperes heated the water of a calorimeter 5° C. in 20 minutes. An unknown current heated it an equal amount in 25 minutes. If the difference in radiation was negligible, what was the strength of the second current? (Aid: The rate of expenditure of energy is inversely as the time.) *Ans.* 8 amperes.

*I.* How much heat will an incandescent lamp of 200 ohms resistance and using .5 amperes, give off per hour? *Ans.* 43,200 calories.

*J.* A copper wire has a current of 24 amperes passing through it, and the difference of pressure at its terminals is 10 volts when its temperature is 75° F. How much more heat will be produced per second in the wire when carrying the same current if its temperature becomes 120° F.? (Aid: 10 per cent more pressure will be used in the second case as the resistance of the wire increases 1 per cent for each 4.5° rise of temperature.) *Ans.* 5.76 calories.

*K.* Five horse power is used in an electrical cook stove. How much heat is generated per minute? (Aid: One calorie = .24 watts for one second.) *Ans.* 53,712 calories.

*L.* If the heat generated by the current in a wire is equal to the power required to lift 300 pounds 11 feet per minute, how many calories are expended per second? *Ans.* 17.9 (approx.).

**114. Temperature of Wire carrying Current.** — The actual rise of temperature on the part of a wire when a current passes through it depends upon several things in addition to the amount of heat produced in it. A long, thick wire and a short, thin wire of the same material, and having the same resistance, will come to very different temperatures when equal currents are passed through them. If there is sufficient difference in their diameters, the thin wire may become red-hot on account of the passage of a current which is only sufficient to make the thick wire appreciably warm.

When a current passes through a wire, a certain amount of heat is produced during every second that the current flows. For a short time after the current is started, the wire rises in temperature, and finally reaches a certain fixed temperature. *When the temperature becomes fixed* it is evident upon a little thought that *as much heat must leave the wire* by **Radiation** to surrounding objects, **Convection** by air currents, or **Conduction** to objects touching the wire, *as is produced by the flow of the current.* If more heat is given to the wire than is carried off by these means, its temperature must rise; and if on account of a decrease in the current the amount of heat given to the wire is less for a time than the amount given off, the temperature must fall until the two are equal again.

The capability of a wire to get rid of heat by radiation and convection depends upon the color and condition of its surface, and also roughly upon the extent of the surface. The amount of heat which leaves any surface in a second also depends upon the number of degrees by which its temperature is higher than that of the air and surrounding objects. The amount of heat which is required to bring a wire to a given temperature also depends upon the capacity of the material for holding heat, or its **Specific Heat**, as it is called. Consequently the actual temperature to which any wire will rise when carrying a certain current can be exactly determined only by trying the experiment.

**115. Effect of Insulating Coverings.** — The fact that the ability of a wire to emit heat is directly dependent upon the extent of its surface causes a wire with an ordinary insulating covering to remain cooler in the open air than a similar wire without the covering, though the two wires carry equal currents.

This seems at first sight exactly opposed to the facts as seen in covered boiler pipes. There is no contradiction, however, because the thickness of the insulation is entirely comparable with the diameter of the wire, and the outside surface of the insulation is therefore so much greater than that of the wire that the additional surface more than makes up for the difficulty which the heat experiences in getting through the insulation; the heat thus finds it easier to leave the wire which has the insulation on it. This effect is most decidedly shown when the outer surface of the insulation is black.

When steam pipes are covered for the purpose of retaining their heat, the thickness of the covering is thin compared with the diameter of the pipes, so that the outside surface of the covered pipes is not much greater than the surface of the pipes when bare. Consequently the effect of the thickness of the covering which is placed in the path of the heat as it leaves the pipe is greater than the effect of the increased surface, and the heat finds it more difficult to leave a covered pipe. This is especially the case because the steam pipes are covered with the very best heat insulators.

When wires are closed up in mouldings or placed under plaster, as is often the case with the electric light wires in buildings, they become very much warmer than when exposed in such a way that they may be cooled by air currents.

The heating effects of electric currents flowing through conductors are depended upon for the operation of incandescent lamps, electric heaters, and some other devices that are described in later pages.

**116. Physiological Effects of Electric Currents.** — Electric currents cause various effects besides those of electrochemistry, electromagnetism, and electric heating. These effects are of many kinds, but of small commercial importance, and in most cases seem to be due to some action of the current upon the molecules of the material through which it flows. Some of the effects are undoubtedly due to electrochemical action, though they have often been attributed to some unknown action of the current. One of these effects, which is of sufficient importance outside of the field of purely speculative science to require attention, is the physiological action of the current. Galvani accidentally discovered this action through some experiments performed upon frogs.

His discovery has been followed up by many scientists down to the present day, and a vast array of facts has been determined relating to the effects of currents on living organisms.

The researches of these scientists have shown that *protoplasm*, which is the fundamental basis of all living bodies, has the power of contracting when an electric current passes through it. Moreover, a living animal nerve is always excited to action by the passage through it of an electric current from an external source. If the terminals of a battery cell are touched to the tongue, a peculiar taste may be noticed. This taste may also be caused by laying a copper and a silver coin upon the tongue with their edges touching. In this case a current is set up through the metals, the saliva of the mouth serving as the fluid. If the terminals of a battery cell are touched to the temples, or placed so that the current flows from the forehead to the hand, flashes of light may sometimes be perceived, due to the excitation of the nerves of the eye by the current. In the same way the nerves of smell and hearing may be excited.

When a sufficiently powerful electric current is passed through the ordinary nerves, a feeling of tickling, pricking, or pain may be observed. If the current is sufficiently strong, it may cause a very painful muscular contraction, and if excessive the current may cause death. The muscular and nervous effect due to a strong current is ordinarily called a **Shock.** The severity of shock depends upon the amount of the electrical current which flows through the body, but it also depends largely upon the physiological condition of the person who receives the shock.

It has been found that electric currents naturally exist in the living muscles and nerves of animals, and that muscular exertion seems to cause them. These currents disappear with the death of the animal, which possibly shows that the electric currents have some function in the action of the nervous system. The capability of delivering quite a severe electric shock to marauders exists in certain animals — notably the Gymnotus, — but their means of producing the electric discharge has not been disclosed to man.

The physiological action of electric currents gives a good basis for their use in the treatment of certain diseases, and they have been used with marked success in some cases. The electrolytic effects of steady battery currents may be used for reducing swellings, hardening tissues, injecting medicine through the skin, and other purposes. Rapidly alternating currents and high pressure static discharges have proved of service on account of their effect upon the nerve system. The use of a cautery blade heated by electricity has become quite common. The miniature electric light in combination with a proper system of mirrors has made it possible to examine many of the internal cavities of the body. It may be of interest to add that a great proportion of the electromedical appliances that are commonly advertised, such as electric belts, magnetic brushes, etc., are not only absolutely useless, but in many cases harmful. Indeed, electric treatment should never be applied except under the immediate direction of a trained physician. The indiscriminate use of electrical treatments of any kind is likely to do more harm than good.

**117. Thermo-electric Currents.** — In 1821, Seebeck, a Russian by birth and German by education, while carrying on a series of electric experiments, under the inspiration of the work of Oersted (Article 119), found, when he held in his hand one of the junctions of a circuit composed of antimony and copper strips, that the needle of the galvanometer in circuit was deflected. This he ascribed to the heating of the junction, since if he held his hand at any other place than a junction there was no deflection. He also found that cooling one of the junctions also caused a deflection. The manifestations of this phenomenon, and those allied to it, are called **Thermo-electric Effects**.

It has been found that electricity may be generated by heating or cooling a junction in a circuit composed of any two dissimilar materials, such as two metals, two liquids, a metal and a liquid, or even a single material which has slightly different physical characteristics in its parts. Thus, for instance, a copper wire may be annealed in part of its length, when, if the region between the annealed and unannealed part is heated, a current will be caused to flow through the circuit.

If the joints in the circuit of unlike metals are heated equally, no electromotive force is set up, and no thermo-electric current flows. *A difference in the temperatures of the junctions is essential to the exhibition of the effect.*

Thirteen years later than Seebeck's discovery, Peltier, a Paris watchmaker, made an allied discovery — that an electric current, when it flows across the junctions of unlike metals in a circuit, may either heat or cool the junction. This **Peltier Effect** is the reverse of the thermo-electric effect discovered by Seebeck. Some years later, Lenz actually succeeded in cooling a junction by the Peltier effect to so low a temperature as to cause water to freeze.

Lord Kelvin, somewhat later, made additional discoveries, and with others added to the sum of experimental knowledge regarding thermo-electric effects, but the cause of the phenomena has never been discovered.

**118. The Thermopile.** — Different materials set up very different thermo-electric pressures, but the pressure of a single junction of any pair of metals is so small that it is desirable to measure it in microvolts (millionths of a volt). Antimony and bismuth furnish the highest pressure of any of the metals that can be used satisfactorily. Since the pressure which one joint, or **Couple** as it is called, sets up is very small, a number of couples are often connected in series. When these are laid up side by side, so that alternating junctions may be heated and cooled, the arrangement is called a **Thermopile**. Figure 53 shows a thermopile and the series of couples composing it. For making a thermopile, or **Thermo Battery**, as it is also called, for furnishing comparatively large currents, German silver and an alloy of antimony and zinc may be used to advantage, since they will stand a high temperature. One couple of such a battery will give about .04 of a volt when the hot junctions are heated to as high a temperature as the metals will stand without injury, and the others

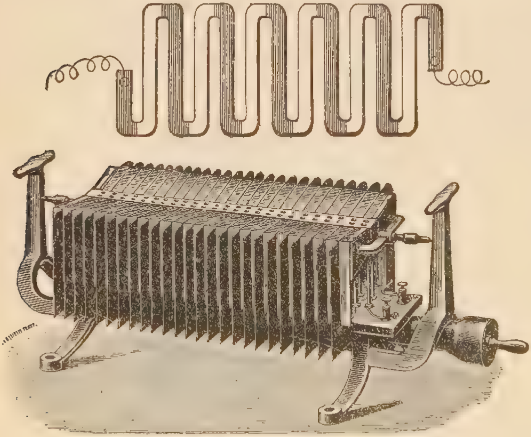

FIG. 53. — Diagram and Perspective View of a Thermopile.

are kept at the temperature of the air. The necessary waste of heat which occurs in using thermo-batteries makes them of little commercial value, though they have proved of great service in some lines of scientific investigation on account of the steadiness of the current which they produce, and the convenience attending their use.

## QUESTIONS

1. What is the foot pound?

2. What is the joule?

3. Compare work done by water flowing under pressure to electricity flowing under pressure.

4. If 50 coulombs of electricity flow under a pressure of 10 volts, how many joules of work will be done?

5. What quantity of electricity must flow under a pressure of 2 volts to do 50 joules of work?

6. If 20 coulombs do 20 joules of work in flowing through a wire, what is the pressure?

7. What is power?

8. What is a horse power?

9. How many foot pounds of work are done by a horse power working for one minute?

10. How may the power of a waterfall be calculated? Of a steam engine?

11. What is the unit of electric power?

12. Who was the watt named after?

13. How many watts are there in a horse power?

14. What is a kilowatt?

15. How many watts will be expended if a current of 10 amperes flows under a pressure of 10 volts?

16. Into what other form of energy is electrical energy converted by the passage of a current through a resistance?

17. What is the law of conservation of energy?

18. What finally becomes of the energy put into a ball when it is thrown into the air?

19. What is the mechanical power transmitted by the foot to a sewing machine finally converted into?

20. A battery cell has its terminals connected by a wire. What two transformations does the chemical energy of the cell undergo?

21. A coal pile feeds a boiler, the boiler supplies steam to an engine, the engine drives a dynamo, the dynamo drives a motor, and the motor runs a sawmill. Name the various transformations passed through by the energy originally in the coal.

22. There are losses of the power available for useful purposes, in each of the transformations of question 21. What becomes of the lost power?

23. Is the power lost for useful purposes in any transformation ever destroyed?

24. Can any kind of a machine be run without some of the energy that is given to it being converted into a useless form of heat energy?

25. Is a perpetual motion machine possible? (A perpetual motion machine is one that requires no energy to keep it going.)

26. What becomes of the energy used in sending a current through a wire?

27. What is the power in watts, lost in the resistance of a wire, equal to in terms of the resistance and current?

28. What is the power in watts, lost in the resistance of a wire, equal to in terms of the resistance and pressure?

29. What is the pressure in volts, required in sending a current through a wire, equal to in terms of the resistance and current?

30. If the same current passes through three wires of equal length, but having cross sections in the proportion of one, two, and three, what will be the relative losses by heating in the wires?

31. What is a calorimeter?

32. Why is a calorimeter double walled?

33. What is a calorie?

34. What is Joule's Law?

35. What is the amount of heat in calories that will be expended in a wire, in terms of its resistance, the current, and time?

36. How can a calorimeter be used as a current-measuring instrument?

37. How much heat will 2 amperes produce per second, in calories, in flowing through a wire with a resistance of 1 ohm?

38. What effect has the form of a wire upon its temperature when a current is flowing through it?

39. What are radiation, conduction, and convection, in reference to heat?

40. What is specific heat?

41. If a current is passing through a wire, why will the wire rise to a certain temperature and not continue indefinitely to grow hotter?

42. What are the elements upon which the dissipation of heat from a wire depend?

43. If wire is closely wrapped with insulating material, will it become hotter under the influence of a given current than it would if bare? Why?

44. Compare the dissipation of heat from insulated wires and covered steam pipes.

45. Will a wire placed within a moulding carry as large a current without overheating as will be the case if it is exposed to the air?

46. Will heat be dissipated more rapidly into the air from a wire at a temperature of 200° than it will when the wire is at 100°?

47. What are some of the physiological effects of the electric current?

48. For what purposes is electricity used in medicine?

49. What is thermo-electricity?

50. When were the phenomena of thermo-electricity first noticed? By whom?

51. What is the Peltier effect?

52. What is a thermopile?

# CHAPTER IX

## ELECTROMAGNETISM

**119. Historical.** — The real connection which exists between magnetism and currents of electricity was not made generally known until Oersted, a Danish scientist, published the fact in 1820 that a magnetic needle is disturbed by the presence of an electric current in its neighborhood. This fact had really been discovered earlier, but it did not become generally known, and its importance had not been recognized. It had also been known that under some conditions lightning discharges had magnetized steel needles, but the conditions had not been successfully reproduced by experimenters. The publication of the results of his experiments, by Oersted, led a number of scientists to turn their attention during the early part of the nineteenth century to a determination, as complete as was then possible, of the exact relation existing between electricity and magnetism. We are, therefore, entirely justified in crediting Oersted with the original discovery of the magnetic effect of the electric current — one of the epoch-making discoveries of the world.

**120. Effect of a Current flowing near a Magnetic Needle.** — If a magnetic needle is placed above or below a wire which carries an electric current, *the needle will turn on its pivot so as to set itself as nearly as possible at right angles to the wire.* This may be readily tried by connecting a short piece of copper wire to one or two cells of a gravity battery and holding the wire above the needle (Fig. 54) while the current flows through it. The effect on the needle may be made most evident by making and breaking the electric circuit, which will cause the needle to swing back and forth, since it will be deflected every time the circuit is closed and will return toward its position of natural rest when the circuit is broken. The current in the wire has the greatest effect in causing the needle to deflect from the north and south position when the wire also lies in a north and south direction — that is, when the wire is parallel with the needle.

The force of the earth's magnetism is what causes the needle to turn into a north and south position and stay there when it is undisturbed by other magnetic effects. When the electric current is placed so as to flow near the magnetic needle, *the needle is affected by the force of another magnetic field which is set up by the current,* and which tends to make the needle set itself at right angles to the wire carrying the current. The needle takes an intermediate position where the effect of the two magnetic forces (that due to the earth and that due to the current) balance. Its new position, therefore, depends upon the magnitude of the force due to the magnetism set up by the current as compared with the force of the earth's magnetism.

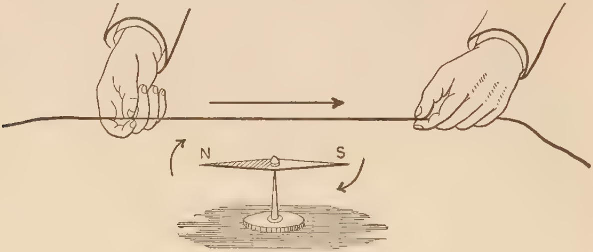

FIG. 54.—Wire held above Magnetic Needle.

**121. Direction and Strength of an Electromagnetic Field.**—Magnetism set up by an electric current is called **Electromagnetism**; but this term is merely a convenient indication of the immediate source of the magnetic force, since the magnetic force produced by a permanent magnet such as a magnetized piece of steel or the earth and that produced by an electric current are exactly alike. The direction of the magnetic force due to electromagnetism is always at right angles to the direction of the current which produces the magnetism, and the lines of force in the magnetic field due to the current in a cylindrical wire must, therefore, be circles surrounding the wire. *The strength of the magnetic field at any point due to an electric current near by depends directly upon the strength of the current and inversely upon the average distance of the current from the point.* The reason why a magnetic field is set up by an electric current is entirely unknown; merely the experimental fact and its applications are known.

The magnetic field which surrounds a current may be graphically shown in a way similar to that used to show a field around a magnet.[1] A stout copper wire may be passed vertically through a hole in a horizontal sheet of stiff paper. If iron filings are sprinkled upon the paper, they will arrange themselves in circles around the wire when a current is passed through it. (Fig. 55.) If a small magnetic needle or compass is placed on the paper with its centre over a line of filings, the needle will tend to stand at a tangent to the line (Fig. 56). An independent magnet pole (if such a thing were physically possible) would tend to move continuously around the wire along any one of the lines upon which it might be placed.

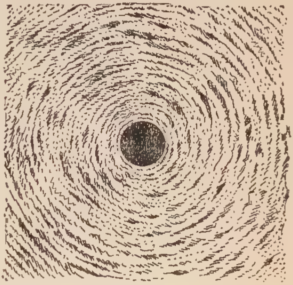

FIG. 55. — Picture of Iron Filings showing the Distribution of Magnetism around a Wire carrying an Electric Current. The black dot represents a cross section of the wire.

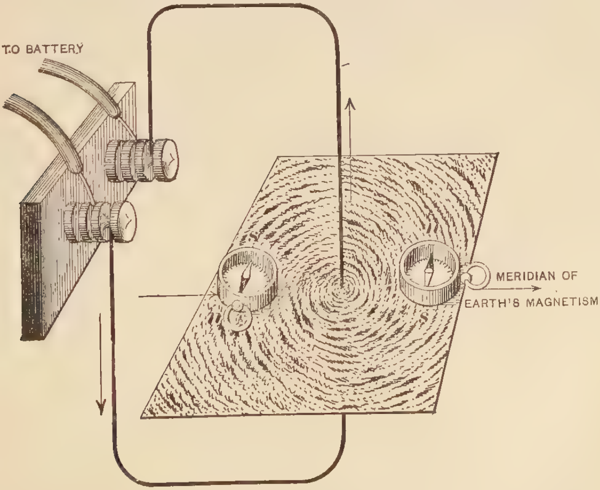

FIG. 56. — Direction of Magnetic Lines of Force which surround an Electric Current shown by Small Compass Needles, *NS*.

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[1] Articles 80 and 84.

The direction in which the magnetic needle points when near a wire carrying an electric current depends upon which side of the wire it stands, and upon the direction in which the current flows in the wire. In Figure 56 it is evident from the position of the magnetic needles, the black ends of which represent north poles, that the positive direction along the lines of force is there left-handed, or opposite to the direction of motion of the hands of a clock. If the direction of the current were reversed, the magnetic needles would also reverse their directions, showing that the positive direction of the lines of force has a fixed relation to the direction of the current.

**122. Rules for determining the Direction of a Field around a Current.** — There are various ways of remembering the relation between the positive direction of the lines of force and the direction of the current which produces them. One is to consider an ordinary right-handed screw which is being screwed into or out of a block (Fig. 57). *If an electric current is considered as flowing through the screw in the direction which the screw moves through the block, then the positive direction of the lines of force is shown by the direction in which the screw turns.* Instead of a screw and nut, a corkscrew being screwed into or out of a cork may be thought of. The rule may be applied to Figure 54 by way of illustration.

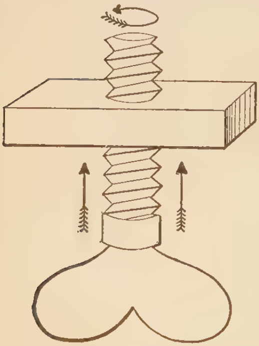

FIG. 57. — Illustration by Screw and Nut of the Relation between the Directions of Current and the Magnetism produced by it.

Another way of remembering this relation is according to a rule proposed by Ampère, after whom the unit of electric current was named. *Suppose a man lying in the wire with his head down the electric stream (swimming with the electric current); then if he faces a magnetic needle placed near the wire, the north pole of the needle will tend to turn toward his left hand.*

This rule may also be applied by way of illustration to Figure 54. The man must be supposed to be lying flat on the wire with his face toward the magnetic needle and his head pointing toward the right-hand edge of the page, since he is swimming with the current. His right hand is then toward the reader and his left hand away from the reader. The curved arrows show that the north pole of the needle tends to turn toward his left hand.

This relation between the direction of the current flow and the deflection of a magnetic needle gives a ready method for determining the direction of the current in a wire, the only indicator which is required being a small compass. The compass may be placed under the wire and the direction toward which its north pole turns noted. Then an application of one of the rules gives the direction of the current. This means is very commonly used in electrical manufacturing establishments and in testing laboratories.

Another rule for illustrating the relation between the direction of the current in a wire and the direction of its lines of force is this: Grasp the wire with the **right hand**, the thumb being extended along the wire, and the fingers being wrapped around the wire; then *the fingers point in the positive direction along the lines of force when the thumb points in the direction of flow of the current.*

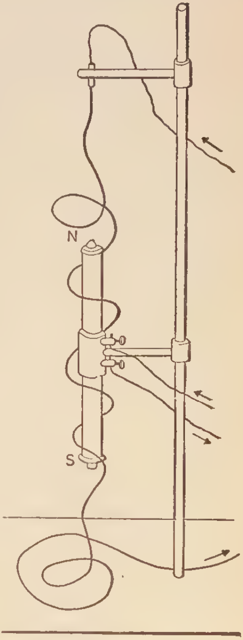

FIG. 58. — Illustration of the Effect of Magnet on Flexible Wire carrying Electric Current.

**123. Mutual Force acting between a Magnet and Current.** — Since we know that a force acting between two bodies always affects them both,[1] we may expect that a wire which carries a current will tend to move when brought near a fixed magnet. This may be readily shown by suspending a very flexible conducting wire near a fixed magnet (Fig. 58). When a current is passed through the wire it will wind itself around the magnet. If the current is reversed, the wire will unwind and then wind around the magnet again, but in the opposite direction.

The motions of the wire and the magnet are due to the apparent

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[1] Article 84.

*tendency of magnetic lines of force to move out of a position where they are not parallel with each other and into a position where they are parallel with each other and in the same direction.*[1]

**124. Solenoids.** — By applying Ampère's rule, we see that if a wire carrying a current is passed above a magnetic needle, and then is turned back and passed below the needle, both the top and the bottom branches tend to deflect the needle in the same direction, so that the effect on the needle is increased. (See Fig. 59.) If the two branches are equally near the needle, they act upon it with equal force, and thus the total force on the needle is doubled. By coiling the wire about the position of the needle, each additional turn will cause an additional deflecting force. In this way the magnetic effect of a current may be greatly multiplied. It has already been said that the magnetic force at a point due to a current near it depends upon the strength of the current.[2] We now see that *when a current is coiled around a point the force depends upon the strength of the current multiplied by the number of turns in the coil. This product of the current by the turns is usually called "current turns" or "ampere turns."*

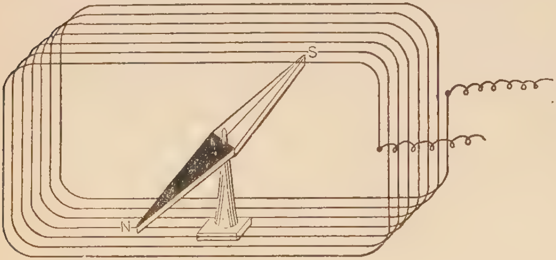

FIG. 59. — Illustration of Magnetic Needle placed at Centre of a Coil of Wire.

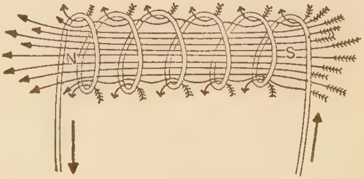

FIG. 60. — Picture of Loose Solenoid with its Lines of Force.

When a wire carrying a current is coiled into a ring or helix, the lines of force which surround each turn seem to join together so that they belong to the coil or *winding* as a whole (Fig. 60). Such coils are often called **Solenoids.** *Such coils, when a current is passed through them, exhibit all the magnetic effects which are shown by steel magnets.* They attract and repel magnets and other solenoids, and attract pieces of iron. If suspended so that they are free to swing, they turn into a north and south position exactly like magnets. Figure 61 shows an iron filing illustration of the magnetic field within a solenoid. The illustration is the longitudinal section taken along the axis of the solenoid, and the black dots represent the individual conductors of the coil.

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[1] Article 86.

[2] Article 121.

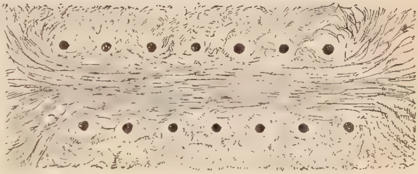

FIG. 61. — Picture of Iron Filings showing the Distribution of Magnetism inside and outside of a Solenoid.

By applying either of the rules for finding the relation between the direction of a current and its magnetic field, the polarity of a solenoid may be readily found. This relation is also expressed as follows: *If a person face one end of a solenoid, and the current is flowing in a direction counter to the direction of the hands of a clock, the north pole of the solenoid will be nearer him. If the current flows clock-wise, the south pole will be nearer him.*

This magnetic effect of coils or solenoids led Ampère to suppose that all magnetism is caused by electric currents. He, therefore, suggested that the molecules of magnetic materials, and possibly of all materials, have little electric currents flowing around them which make them into magnets. This is called "Ampère's theory" of magnetism.[1] If the theory is correct, it gives a ready explanation of why magnetism is found in various materials, but it still leaves unexplained the reason for the existence of the electric currents in the molecules, and also why the electric current causes magnetism. Ampère's theory and theories of magnetism advanced by other scientists have been before the scientific world for many years, but their correctness has not yet been either proved or disproved. We must, therefore, rest for the present with the evidence that the molecules of magnetic materials appear to be of a magnetic character, while those of non-magnetic materials appear not to be magnetic.

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[1] Article 81.

## QUESTIONS

1. Who discovered the magnetic effect of the electric current? At what date?

2. State why you consider Oersted's discovery of great value to the world.

3. If a magnetic needle is placed near a wire carrying a current, what position will it take?

4. If a magnetic needle lies parallel to a wire placed in a north and south direction, what two forces act upon it when a current is sent through the wire?

5. Is it possible to measure the strength of a current by its magnetic effect upon a needle?

6. Why does a current tend to deflect a needle?

7. What is electromagnetism?

8. Is the magnetism created by an electric current in any way different from the magnetism of a magnetized steel bar?

9. What is the direction of the magnetic lines with respect to the direction of current which sets them up?

10. Upon what depends the strength at any given point of a magnetic field which is set up by a current?

11. How much stronger is the magnetic field, set up by a current, 1 inch from a straight wire carrying the current, than it is 2 inches away?

12. If one wire carries three times as much current as another, how much stronger will the magnetic field be 1 inch from the former than it is one inch from the latter?

13. A compass is placed 1 cm. above a straight wire which lies north and south and carries a current of 1 ampere. The deflection is found to be the same as it was when the compass was placed two centimeters above another wire lying in the same direction. How much current was flowing in the second wire?

14. How can it be shown that the lines of force about a cylindrical wire carrying a current are in the form of circles?

15. Why will a magnetic needle reverse the positions of its poles when placed on opposite sides of a current-bearing wire?

16. Give the "screw rule" for determining the direction of the field about a current.

17. Give the "swimming rule." Give the thumb and hand rule.

18. How can the direction of a current be determined by means of a compass?

19. A compass needle tends to stand with its north pole to the east when placed under a wire lying in a north and south direction. Determine the direction of the current in the wire by the swimming rule.

20. Answer Question 19 by means of the screw rule.

21. If you are standing beside and facing a wire in which a current flows from left to right, and you place a compass needle over the wire, will the north pole tend to turn toward you or away from you?

22. While standing beside and facing a wire you place a compass under it and find that the north pole of the needle moves away from you. Determine whether the current is from left to right or vice versa.

23. What happens to a flexible wire carrying a current when it is brought near a magnet?

24. Why does a flexible wire carrying a current tend to wind about a magnet?

25. What position do the lines of force of two fields tend to take when the fields are brought together?

26. Describe two experiments that show that the current flowing in a wire and a magnet both tend to move when they are brought near each other.

27. What is a solenoid?

28. Why will a needle deflect when placed within a turn of wire?

29. What effect on the magnetic field of an electric current is produced by winding the wire which carries the current into a solenoid of many turns?

30. Upon what does the strength of field in a solenoid depend?

31. What are ampere turns?

32. How many ampere turns has a coil of twenty turns which carries one-half an ampere?

33. How do the lines of force arrange themselves in and about a solenoid?

34. In what ways can a solenoid be compared to a permanent magnet?

35. What led Ampère to advance his theory of magnetism?

36. What is the "clock" rule for determining the relative direction of current and magnetism in a solenoid?

37. If the north pole of a compass needle is attracted toward the end of a solenoid, before which you are standing, what is the direction of current in the coil?

38. If you wish to have a south pole at the bottom of a vertical solenoid, how must the current be made to flow?

**125. Magnetizing Effect of a Solenoid upon Magnetic Materials.** — If a bar of hard steel is placed in a solenoid through which a current is passing, it becomes strongly magnetized, and it remains permanently magnetized when the current is stopped or the steel is withdrawn from the solenoid. This effect is exactly the same as would be obtained by touching the steel with a permanent magnet, but the magnetic effect of a solenoid with many turns of wire may be made much greater than that of any permanent magnet, and the steel may, therefore, be more readily saturated by the solenoid.

In Article 89 it is said that a magnetomotive force is necessary to maintain magnetism in a circuit. Evidently a solenoid creates such a difference of magnetic potential or pressure, or it could not maintain its magnetism. It has been found by experiment that one ampere turn sets up nearly one and one-quarter units of magnetic pressure. Thus, if we had a solenoid of 25 turns with a current flowing through it of 4 amperes, nearly 125 units of magnetic pressure would be created. This relation may be expressed in the following formula, for convenience: —

$$M = 1.257\ nc.$$

where $M$ is the magnetic pressure, and $nc$ the number of ampere turns, $n$ being the turns and $c$ the current. The exact value of the constant (1.257) is equal to $\frac{4\pi}{10}$ or 1.2566+. For many purposes the first three significant figures give sufficient accuracy, and the formula is then very convenient.

Now, if a bar of soft iron is placed in the solenoid, it becomes even more strongly magnetized when the current is turned on than did the steel bar. When the current is turned off, the soft iron loses nearly all of its magnetism. If the bar is made of very soft Swedish iron, its coercive force is so small that the least tap, after the current is shut off, shakes practically all of the magnetism out of it. Harder and less pure iron retains a little of the magnetism — the amount depending upon the quality of the iron. The magnetism which is retained by iron after it has been magnetized, and the magnetizing influence has been removed, is called **Residual Magnetism.** The so-called permanent magnetism of hard steel magnets is residual magnetism very firmly retained by the great coercive force of the hard steel.

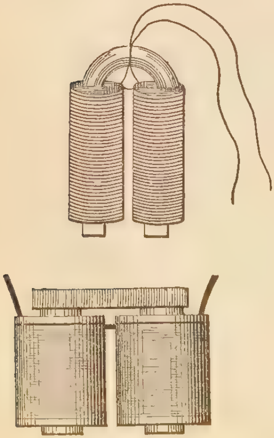

FIG. 62. — Two Horseshoe Electromagnets.

**126. Electromagnets.** — When a coil of wire is wound around a piece of soft iron or steel for the purpose of getting a magnetic field, the combination is called an **Electromagnet.** A piece of hard steel might be used instead of soft iron, but in this case the amount of magnetism created by a given current in the coil, or number of ampere turns, would be much less than is produced in soft iron. Soft iron or steel is universally used, therefore, in electromagnets.

Electromagnets are of the greatest value in the electrical industries because they can be built of practically any desired size and form, and of enormous magnetic strength. The magnets of commercial dynamos and electric motors are always electromagnets. Figure 62 shows two forms of **Horseshoe** electromagnets.

The property of soft iron through which it becomes strongly magnetized when it is placed within a solenoid, and then loses its magnetism when the current is broken, was discovered by William Sturgeon of England in 1825. Very shortly after Oersted's discovery, Sir Humphry Davy, Arago, Ampère and others had magnetized steel needles by placing them in solenoids, but it was reserved to Sturgeon, an otherwise little known scientist, to make the discovery of that most important property of soft iron — the dependence of its magnetism upon the continued presence of the magnetizing force and the controllability of its magnetism by varying the magnetizing force. Like Davy, Faraday, Henry, and others of the world's great discoverers in physical science, Sturgeon, as a boy, was an artisan apprentice, and gained his knowledge of science through study and experiment in his unemployed hours.

At the time of the discovery of the electromagnet nothing was thought of its great commercial future; but it was welcomed with the highest scientific interest. At that day the laws of electric circuits were unknown, the common insulated wire of to-day was not made, and the manufacture of an electromagnet was a matter of much labor. Moreover, the only sources of current were, at first, plain zinc-copper cells, and later, Grove, Daniell, or similar types of galvanic cells. Many electromagnets were soon made, however, and their effects were carefully studied by enthusiastic scientists, in spite of the difficulties to be overcome. By the year 1845, little more than a half century ago, the investigators had succeeded in overcoming their lack of experimental facilities and had mapped out the laws of magnetic circuits very much as we know them at the present time. Thus was laid the foundation of the profession of electrical engineering.

**127. Curve of Magnetization.** — If currents of different strengths are sent through the coil of an electromagnet, the strength of magnetism produced will vary with the current, below the saturation of the iron, though not in direct ratio; and after the iron is saturated very little additional magnetism will be set up by increasing the current. Figure 63 shows by means of a curve the typical relation between ampere turns and magnetism. Distances on the horizontal line are proportional to the ampere turns, and on the vertical line to the number of magnetic lines of force per square centimeter in the iron. Such a curve is called the **Curve of Magnetization** of the electromagnet. *A*, in the figure, represents the region in which the saturation of the iron is reached. Beyond this region, the curve shows that any increase of ampere turns makes only a relatively slight increase in magnetism. When the current is withdrawn, the coercive force will retain a proportion of residual magnetism in the iron, and, therefore, if the current is removed little by little, a second curve will be made as shown by *C D*, in Figure 64. The poorer, or harder the iron, the greater will be the difference between the curves *C D* and *B C*.

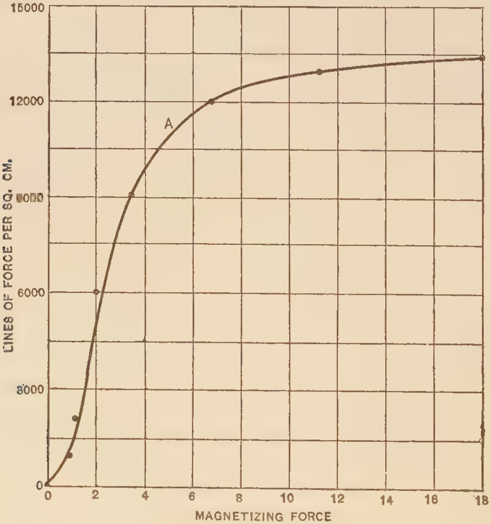

FIG. 63. — Curve of Magnetization of Soft Iron.

**128. Hysteresis.** — The difference between the curves is caused by the iron apparently holding on to its preceding magnetic state, and the effect is called **Hysteresis**, as suggested by Professor J. A. Ewing, during a remarkable series of investigations and discoveries in electromagnetism which were begun in 1881. One of the causes of hysteresis is the coercive force in the iron, and one of its effects is the retention of residual magnetism by a piece of magnetized iron after the magnetizing force has been withdrawn.

**129. Magnetic Permeability.** — From what has preceded we may see that a solenoid in which a current flows and which contains a soft iron or steel core is a stronger magnet than a similar solenoid containing a hard steel core, and it is a very much stronger magnet than a similar solenoid containing no core. Remembering that, according to our idea of lines of force, the strength of the magnetism of the solenoid and core depends on the number of lines of force which pass through the solenoid; then, since so many more lines of force pass through a solenoid when a hard steel bar is placed in it than pass through it when the space within the solenoid is simply occupied by air, we may conclude that lines of force are more readily set up in steel than in air; and since a soft steel core causes more lines of force to pass through a solenoid

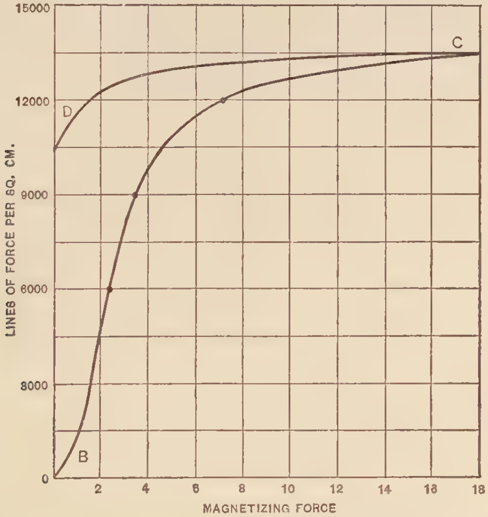

FIG. 64. — Curve of Magnetization, *BC*, and Curve of Demagnetization, *CD*, of Soft Iron.

than does the hard steel core, we may also conclude that lines of force are still more readily set up in soft steel.

The relative ease with which magnetic lines of force may be produced in a body is called its **Permeability**. As a matter of convenience it is usual to say that *the permeability of air is unity* (1). As compared with this, the permeability of soft iron or steel is very great; it may be several thousand times, and in some cases many thousand times, as great.

The permeability of all materials, except a few highly magnetic ones, is very nearly constant at the value of unity, or the same as that of air; but the permeability of the magnetic materials varies. For instance, the permeability of iron increases rapidly as the iron is being magnetized until a certain magnetic density is reached, and then if the magnetic density is crowded still higher, the permeability rapidly decreases. Typical "permeability curves" for wrought iron, soft steel castings, and cast iron, which show the relation between magnetic density and permeability, are shown in Figure 65. The proper division between

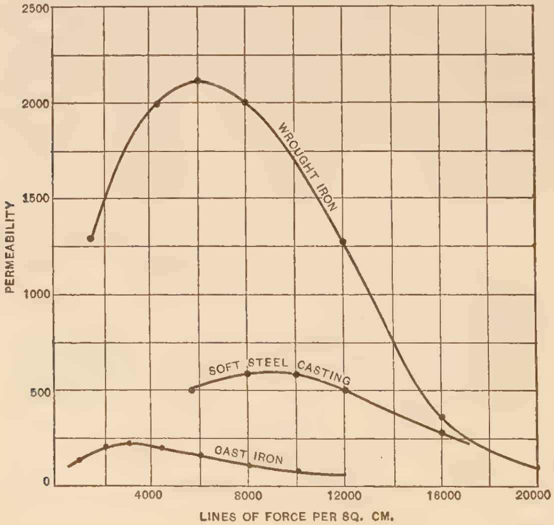

FIG. 65. — Permeability Curves of Specimens of Wrought Iron, Soft Steel Castings, and Cast Iron.

materials that are called paramagnetic and those that are called diamagnetic[1] depends upon whether their permeability is greater than unity or is slightly less.

We may divide materials into good conductors of magnetic lines of force, or good magnetic conductors, and poor magnetic conductors. There are, however, no materials which may be regarded as magnetic insulators, in the way that we regard some materials as being practical insulators of electricity; and all materials, and a vacuum as well, are to a certain degree magnetic conductors.

The permeability of a material may be called its **Specific Magnetic Conductivity**, that is, the magnetic conducting power of a block of the material which is one centimeter long and has an area of one square centimeter. *The actual magnetic conductivity of any piece of material decreases with the length and increases with the cross section of the piece.* This may be likened to electrical conducting power, or conductivity, which is described in Chapter VII.

### PROBLEMS

*A.* How many units of magnetic pressure will 15 amperes passing through a coil of 30 turns set up? *Ans.* 566 (approx.).

*B.* For the purpose of magnetizing an iron bar we wish 1257 units of magnetic pressure, we have a coil of 250 turns and 10 ohms resistance. How many volts pressure must we apply to the coil? *Ans.* 40 (approx.).

*C.* The copper wire coil of an electromagnet has 1000 turns, each being 18 in. long. The wire is of 1050 circular mils cross section. If the coil is connected to a dynamo which furnishes it 50 volts pressure, how many units of magnetic pressure will be set up? *Ans.* 4190.

*D.* Four Daniell cells are connected to a solenoid of 1000 turns and 4 ohms resistance. The cells each set up a pressure of 1.1 volts and have an internal resistance of 4 ohms. How much magnetic pressure will be produced when the cells are arranged with 2 sets in parallel of 2 cells in series? *Ans.* 346 units (approx.).

*E.* If in Example *D* the cells had all been in series, what would have been the magnetic pressure? *Ans.* Nearly 276 units.

*F.* Two coils have respectively 100 and 1000 turns and are of 1 and 10 ohms resistance. What will be the relative magnetic pressures set up in them when the coils are supplied with the same electric pressure? *Ans.* They will be equal.

**130. Magnetic Reluctance.** — The reciprocal of magnetic conducting power may be called **Magnetic Resistance**, but the word **Reluctance** is usually applied to it; and any path through which lines of force pass may be called a **Magnetic Circuit.** These terms may be recognized as entirely analogous to those applied to the case of electric currents and which are described in earlier chapters.

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[1] Article 75.

## PROBLEMS

*A.* A piece of iron 200 cm. long and 100 sq. cm. in cross section has a permeability of 1000 units at a certain magnetization. What is the reluctance? (Aid: By the analogy to electric resistance we can write

$$\text{Reluctance} = \frac{1}{\text{Permeability}} \cdot \frac{\text{Length in centimeters}}{\text{Cross section in square centimeters}},$$

or using symbols to represent those quantities,

$$P = \frac{1}{\mu}\frac{L}{A},$$

$\frac{1}{\mu}$ being equivalent to specific electrical resistance. Substituting the values given in the example, the result is easily obtained.) *Ans.* .002 of a unit.

*B.* A ring of soft steel has a permeability of 500 at a given magnetization, and a length of 100 cm. How large must be its cross section if its reluctance is to be .004 units? *Ans.* 50 sq. cm.

*C.* The air space between a magnet and its keeper is ½ cm. long by 20 sq. cm. in cross section. What is the reluctance of the air ($\mu = 1$)? *Ans.* .025 unit.

*D.* A ring is made up of two curved bars, one of cast iron having a permeability of 100, and the other of wrought iron having a permeability of 1000 at a desired magnetization. Both pieces are 50 cm. long and 25 sq. cm. in cross section. What is the reluctance of the magnetic circuit formed by the ring at the given magnetization? (Aid: Add the reluctances of the two pieces.) *Ans.* .022 unit.

*E.* A magnetic circuit is made up partly of a curved bar of iron 200 cm. long by 50 sq. cm. in cross section, and having a permeability of 1000 at the required magnetism, and partly of an air space 1 cm. long by 50 sq. cm. in cross section. What is the reluctance of the magnetic circuit at the required magnetization? *Ans.* .024 unit.

**131. Magnetic Pressure and the Magnetism set up by It.** — By similarity with electric circuits we may say that it takes some force to set up lines of force in a magnetic field or magnetic circuit. We may call this **Magnetomotive Force** or **Magnetic Pressure** (as already described in Articles 89, and 125), terms which are similar to electromotive force and electrical pressure. *The number of lines of force in any magnetic circuit is equal to the magnetic pressure divided by the reluc-*

*tance of the circuit;* and it can be shown mathematically, as has already been set forth, that the *magnetic pressure in a complete magnetic circuit is equal to the number of ampere turns multiplied by a constant which is nearly equal to* $1\frac{1}{4}$. This may be set down in the form of a formula, in which $N$ is used to represent the number of magnetic lines of force, $M$ the magnetic pressure, $P$ the magnetic reluctance, and $nc$ the number of ampere turns:

$$N=\frac{M}{P}=\frac{1.257nc}{P}.$$

In order that the strongest possible magnetism shall be produced in any magnetic circuit, it is necessary to have the circuit made up as far as possible of material having the highest permeability — that is, soft iron — and to arrange as many ampere turns as possible to set up the magnetism.

The apparent similarities of electric and magnetic circuits, and their really fundamental differences, will be further illustrated in later articles.

## PROBLEMS

*A.* If it is desired to have a piece of iron magnetized with 5000 lines of force per square centimeter, what cross section is required to have a total of 1,000,000 lines? *Ans.* 200 sq. cm.

*B.* A magnetic circuit composed of a ring of iron has a reluctance of .001 unit when 1,000,000 lines of force pass through it. How much magnetic pressure is required to create the 1,000,000 lines? (Aid: From the relation stated above we may write

$$\text{Number of Lines}=\frac{\text{Magnetic Pressure}}{\text{Reluctance}},$$

or using symbols

$$N=\frac{M}{P}.$$

*Ans.* 1000 units of pressure.

*C.* How many ampere turns would be required in Example *B*? *Ans.* 796 (approx.).

*D.* A ring of iron 250 cm. long and 50 sq. cm. in cross section has a permeability of 500 when 10,000 lines of force pass through it per square centimeter. How much magnetic pressure will be required to set up 500,000 lines? (Aid: First find the reluctance.) *Ans.* 5000 units of pressure.

*E.* A ring of iron has a coil of 200 turns wound upon it. The ring is 100 cm. long by 20 sq. cm. in cross section, and has a permeability of 500 when 50,000 lines of force pass through it. How much current will be required to set up this magnetization? *Ans.* 1.98 amperes (approx.).

*F.* A ring of iron, 200 cm. long, is to carry a total of 500,000 lines of force with a magnetic density of 5000 lines per square centimeter. The permeability at that magnetization is 1000. How many turns will be required in the magnetizing coil carrying 2 amperes? *Ans.* 399 (approx.).

*G.* A ring is made up of two curved bars, one of cast iron having a permeability of 100, and the second of wrought iron having a permeability of 1000 at an induction of 5000 lines per square centimeter. Both pieces are 50 cm. long and 25 sq. cm. in cross section. How many ampere turns will be required to set up 5000 lines of force per square centimeter? (Aid: Find reluctance and total number of lines.) *Ans.* 2188 (approx.).

*H.* A magnetic circuit is made up partly of a curved bar of iron 200 cm. long by 50 sq. cm. in cross section, and having a permeability of 1000 at a magnetic induction of 10,000 lines of force per square centimeter cross section; the remaining part is an air space 1 cm. long by 50 sq. cm. cross section. What magnetic pressure is required to set up a total of 500,000 lines of force? *Ans.* 12,000 units.

*I.* In Example *H* how many units of pressure were required to force the lines of force through the iron? *Ans.* 2000.

*J.* If the cross section of the magnetic circuit in Example *H* was doubled, how many lines of force would 12,000 units of magnetic pressure set up? *Ans.* 1,000,000.

*K.* If a coil of 2000 turns and 10 ohms resistance be used in Example *H* for obtaining the magnetic pressure, how many volts must be applied to the coil? *Ans.* 47.7 (approx.).

## QUESTIONS

39. What happens to a bar of steel placed within a solenoid?

40. What is unit magnetic pressure?

41. How many ampere turns are required to set up unit magnetic pressure?

42. How much magnetic pressure will be set up by one-hundredth of an ampere in a coil of one hundred turns?

43. How much magnetic pressure will be set up by 1 ampere in a coil of ten turns?

44. What happens to a bar of soft iron when it is placed in a solenoid?

45. What happens in Questions 39 and 44 if the current is shut off?

46. What is residual magnetism?

47. What is an electromagnet?

48. Which will become the most highly magnetized by the same magnetic pressure, hard steel or soft iron?

49. Describe the form and construction of any electromagnet with which you may be familiar.

50. What characteristic of soft iron did William Sturgeon discover? When?

51. Outline a history of the electromagnet.

52. What is a curve of magnetization?

53. If the current in an electromagnet be increased 1 ampere at a time up to 50 amperes, will the magnetism increase proportionately to the current?

54. If in Question 53, 25 amperes saturated the iron, what would be the effect of the last 25 amperes?

55. If in Question 53 the current be decreased again, will the curve of magnetism be the same as for the rising current? Will it be higher or lower?

56. What is hysteresis?

57. What causes hysteresis? How?

58. Which will a solenoid set up lines of force in most readily, air, soft iron, or hard steel? Which next best?

59. What is permeability?

60. Compare magnetic permeability to specific conductivity of electric conductors.

61. What is the permeability of air, wood, brick, etc.?

62. What are paramagnetic and diamagnetic bodies?

63. Are there any magnetic insulators?

64. What effect have the length and cross section on the magnetic conductivity of a piece of iron?

65. What is magnetic reluctance?

66. How does magnetic reluctance compare with electrical resistance?

67. What is a magnetic circuit?

68. If one magnetic circuit is twice as long and has twice the cross section of another made of the same material, will they be of equal reluctance?

69. If a certain ring of steel has one-tenth the permeability of an equal ring of iron, how much greater will be the reluctance of the steel than that of the iron?

70. Compare magnetic pressure with electric pressure.

71. Construct a law for the magnetic circuit similar to Ohm's Law.

72. A certain ring of iron has a reluctance of 2.5 units. A coil of wire wrapped around it sets up 2500 units of magnetic pressure. How many lines of force will be created in the iron?

# CHAPTER X

## ELECTROMAGNETIC INDUCTION

**132. Pressure induced by moving a Conductor across a Magnetic Field.** — The experiments of Oersted, Davy, Ampère, Arago, Sturgeon, and others showed the intimate relation existing between electricity and magnetism,[1] and also showed that the flow of an electric current always produces magnetism. It remained for the brilliant experimental studies of Michael Faraday, of the Royal Institution, London, and of Professor Joseph Henry, of Princeton College, New Jersey, to make the most important additions to our knowledge of the mutual action between electric currents and magnetism. Within two years after the publication by Oersted of the discovery that a magnetic needle may be deflected by bringing near it a wire carrying an electric current, Faraday had succeeded in producing a continuous motion by means of the effect of an electric current upon a permanent magnet; and it was soon after learned that a wire hung over the pole of a magnet and with its ends in mercury troughs, as shown in Figure 66, would continuously revolve around the pole on account of the mutual attraction between the lines of force belonging to the magnet and to the current in the wire.[2] In the motion thus produced lies the principle of the operation of the electric motors and many of the electrical instruments which prove so useful at the present day.

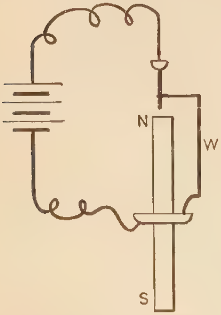

FIG. 66. — Wire *W*, arranged to rotate around Magnet Pole *NS*, through the Mutual Action of Current and Magnet.

The best method of generating an electric current at this time was by means of an electric battery, and the usefulness of the electric motor could be but small as long as it depended for its power upon the consumption of zinc in a battery.[1] To the vigorous minds of Faraday and Henry, the production of motion when an electric current was brought under the influence of a magnet, seemed to suggest a reverse action through which an electric current might be produced by the motion of a wire in a magnetic field. This thought led, shortly after 1830, to the magnificent discovery by Faraday that *a tendency for electric currents to flow is produced in a conductor when it is moved in a magnetic field so as to cut through the lines of force of the field.* That is, *an electric pressure is set up in the conductor when it cuts the lines of force.* The two great experimenters also independently discovered the fact that *any change in the magnetic field around a wire tends to set up an electric current in the wire*, exactly as any change in an electric current which flows in a wire causes a corresponding change in the magnetic field about it.

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[1] Chapter IX.

[2] Article 123.

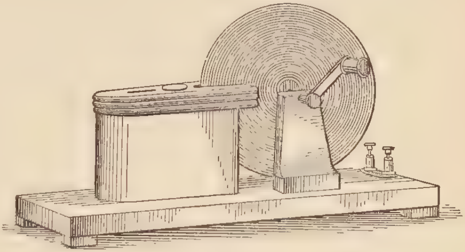

FIG. 67. — Faraday's Disk Dynamo.

In this great discovery lies the principle of the operation of **Dynamo Electric Generators** or **Dynamos**, as they are usually called. Faraday himself in 1831 made what may be called the first model of a dynamo. This consisted of a disk of copper rotated between the poles of a strong magnet (Fig. 67). From this disk a current was collected by copper brushes which rubbed on the edge of the disk and on its shaft.

**133. Early Magneto Machines.** — Faraday's discovery was quickly turned into commercial service, as will be described in a later chapter, and many small machines were made for generating electric currents by rotating coils of wire between the poles of permanent magnets. These machines with permanent magnets are ordinarily spoken of as **Magneto-electric Generators** or **Magnetos** to distinguish them from the ordinary dynamo electric generators or dynamos which have electromagnets.

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[1] Refer to Article 54.

The magnetos which are used for ringing telephone call bells belong to the same class as the early machines.

**134. Magnitude of Pressure set up in a Moving Wire.** — When a wire is moved in a magnetic field so that it cuts lines of force, the action which occurs causes a difference of electric pressure between the two ends of the wire. The magnitude and direction of the pressure which is thus **Induced** depends upon certain fixed relations.

The *magnitude of the pressure depends upon the rate at which the wire cuts lines of force*, that is, *upon the total number of lines of force cut by the wire in a second of time.* When the wire cuts one hundred million (100,000,000) lines of force in every second during its motion, an electric pressure of one volt is set up, and if the wire (like *C* in Fig. 68) is laid across conducting rails which are electrically connected through a galvanometer (shown at *G* in the figure) the galvanometer will indicate, while the wire moves, the flow of a current which has a strength equal to the induced pressure divided by the resistance of the electric circuit made up of the galvanometer, rails, and moving wire.

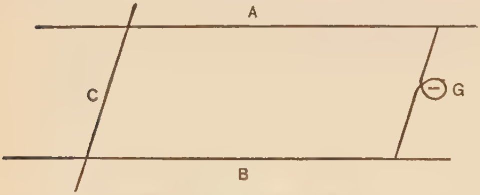

FIG. 68. — Illustration of Rails with Slider to cut Lines of Force.

If the wire cuts through the lines of force at the rate of two hundred millions (200,000,000) to the second, the induced pressure is equal to two volts, and if the wire cuts only seventy-five million (75,000,000) lines each second, a pressure of only three-fourths ($\frac{3}{4}$) volts is set up, and so on, which is according to the rule given above.

The number of lines of force which are cut in a second by a wire moving in a magnetic field depends upon four items.

1. Upon the strength of the field, or the number of lines of force which it contains in each square centimeter.
2. Upon the length of the wire which is in the field.
3. Upon the speed with which the wire moves.
4. Upon the angle with which the wire moves across the lines of

force. If the wire moves diagonally across the lines of force it does not cut through as many lines in a given time as when it moves equally fast at right angles to the lines.

## PROBLEMS

*A.* A wire cuts at a constant rate of speed through a field of 1,000,000 lines of force, 2400 times per minute. How many volts are set up in the wire? *Ans.* .4 of a volt.

*B.* A wire 100 cm. long passes through a magnetic field having an induction of 10,000 lines of force per square centimeter. If it travels at the rate of 1000 cm. per second at right angles to the lines, what pressure will be induced? (Aid: Find number of lines cut per second.) *Ans.* 10 volts.

*C.* Twenty conductors, connected so that their induced pressures are in series, cut through 5,000,000 lines of force at the constant rate of 3,000 times per minute. What is the average pressure set up by the set of conductors? *Ans.* 50 volts.

*D.* One side of a large coil of wire having 100 turns, cuts through a field of 10,000,000 lines of force at an average rate of 2400 times per minute. What is the average pressure developed? (Aid: The turns are in series.) *Ans.* 400 volts.

*E.* A coil of one turn includes 5,000,000 lines of force within its area when the plane of its face is at right angles to the lines. If it is turned over at the rate of 1200 revolutions per minute, what will be the average of the pressure induced during each half revolution? (Aid: each side of the coil cuts all the lines twice in a revolution.) *Ans.* 4 volts.

*F.* If the coil in Example *E* had 25 turns, what would be the average pressure induced? *Ans.* 100 volts.

*G.* If a slider, when cutting at right angles across a magnetic field at a speed of 25 ft. per minute, induces 2 volts, how fast must it go to induce the same pressure when its direction is so inclined to the lines that, at a speed of 25 ft. per minute, it only induces $\frac{1}{2}$ of a volt? *Ans.* 100 ft. per minute.

*H.* A slider 100 cm. long cuts at right angles across a field of 5000 lines of force per square centimeter. If the resistance of the slider is .5 of an ohm and its ends are joined by a wire of negligible resistance, how much current will flow when it is moving at the rate of 300 cm. per second? *Ans.* 3 amperes.

*I.* How much power (in watts) is required in Example *H* to push the slider, supposing there is no friction? *Ans.* 4.5 watts.

*J.* One side of a coil of fifty turns cuts through 5,000,000 lines of force at a speed, during the moment considered, of 2400 times per minute. The resistance of the coil is .2 of an ohm, and the resistance of the external circuit to which it is attached is .8 of an ohm. How much current flows? *Ans.* 100 amperes.

*K.* How many horse power are required to drive the coil in Example *J*? *Ans.* 13.4 (approx.).

*L.* How much pressure is used in the coil and how much in the external circuit of Example *J*? *Ans.* 20 volts. 80 volts.

*M.* What is the pressure at the terminals of the coil in Example *J*? *Ans.* 80 volts.

*N.* What power is used in the coil and what in the external circuit of Example *J*? *Ans.* 2000 watts. 8000 watts.

*O.* How many Daniell cells of 2 ohms internal resistance and 1 volt pressure must be used to equal the power of the arrangement in Example *J*, supposing that the internal resistance of the battery equals the resistance of the coil? How should they be arranged? *Ans.* 100,000 cells. 1000 rows in parallel, each of 100 cells in series.

**135. Direction of Induced Pressure in the Moving Wire.** — *The direction of the induced electric pressure depends upon the direction of the lines of force in the magnetic field and the direction in which the wire cuts through them.* In Figure 69, if the vertical arrows show the direction of the lines of force and the horizontal arrow which lies between the rails shows the direction in which the wire *AB* moves, then the end *B* of the moving wire is positive and the other end negative in pressure. That is, a current will flow around the circuit, composed of the wire and the rails, from *B* through *C* and *D* to *A* and from *A* through the wire to *B*.

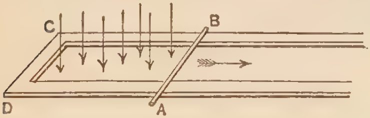

FIG. 69. — Slider and Rails.

*The current flows in the external circuit, BCDA, from the positive or high pressure end to the negative or low pressure end of the wire, and within the moving wire the current flows from the low pressure end to the high pressure end.*

The motion of the wire across the lines of force causes it to act like a pump, which lifts the electric current from its low pressure or suction end to its high pressure or discharge end. In this respect the moving wire acts exactly like a friction machine or a primary battery, such as are described in Chapters III and IV.

If the direction of the wire's motion is reversed, the direction of the current is also reversed. Reversing the direction of the lines of force also reverses the current.

There are various ways of remembering the relation between the direction of the electric current, the direction of the wire's motion, and the direction of the lines of force. One of them is to hold up the right hand, with the thumb pointing straight up, the first finger pointing straight out, and the middle finger turned off to the left (Fig. 70). Now, if the hand is turned in such a direction that the *Thumb* points in the direction of *Motion* of the wire, and the *First Finger* points in the direction of the lines of *Force*, then the middle or *Central Finger* will point in the direction of the *Current* which is set up in the wire by the induced pressure.

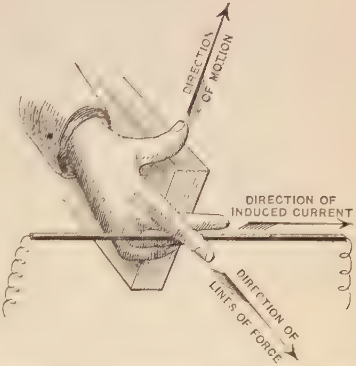

FIG. 70. — Illustration of "Right-hand Rule" for showing Direction of Induced Current.

Another way of remembering this relation is by a modification of Ampère's rule.[1] *If a man lies in the moving conductor so that he looks down along the lines of force (his face is then toward the south pole), and the motion is toward his right hand, he will be floating head first down the current which is set up in the wire.*

**136. Experimental Illustrations.** — It has already been explained[2] that the earth is a great magnet, and that its lines of force, therefore, reach out through all the space within which we live. The induction of electric pressure by a wire cutting lines of force may, therefore, be illustrated by swinging a long wire in the earth's magnetic field. If a wire is suspended across a room, and its ends are attached to a sensitive galvanometer, the needle of the galvanometer will be deflected from side to side when the wire is set to swinging. When the wire moves in one direction, the needle will move to one side of its zero point; and when the wire moves in the other direction, the needle will move to the other side of the zero. This shows that the direction of the pressure induced by the cutting of the earth's lines of force depends upon the direction in which the wire moves across the lines.

If the wire is caused by some means to swing more slowly, the deflections of the galvanometer needle will be smaller, showing that the magnitude of the induced pressure depends upon the velocity of motion of the wire.

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[1] Article 122.

[2] Article 90.

If half the wire is now replaced by a piece of string, and the ends of the remaining half are connected to the galvanometer without practically altering the resistance of the circuit, and the wire is set swinging at about the same speed as before, the galvanometer deflections are reduced to about one-half their former value, showing that the induced pressure depends upon the length of the wire.

These experiments can only be successfully carried out in some such favorably equipped place as a school laboratory, but their description serves to illustrate the effect of moving a conductor across magnetic lines of force. An experiment illustrating the same thing may be made by means of a permanent magnet, a coil of wire, and any galvanometer with a light needle which is obtainable. If the coil, made up of a few turns of wire, is slipped along one end of the magnet at a fixed speed, the galvanometer needle will show a certain deflection. Now, if more turns are added to the coil, which is then moved exactly as before, the galvanometer deflection will be proportionally greater, showing that a greater electric pressure has been induced.

In the case of the coil we have the following condition: each turn cuts the lines of force at a certain rate as the coil is slipped along the magnet, and a corresponding electric pressure is set up in it. Since the turns of the coil are all connected in series, and the electric pressures set up in them are all in the same direction, the electric pressure induced in the whole coil is equal to the sum of the pressures developed in all of its turns. This is exactly similar to the case of an electric battery with its cells connected in series, where the battery pressure is equal to the sum of the pressures of all the cells. Adding additional cells to the battery increases the battery pressure, and adding additional turns to the moving coil increases the total pressure induced in it.

If the connections of some of the cells in the battery are reversed, the pressure at the battery terminals is reduced, and becomes equal to the difference of the pressures which are developed by the cells connected in one way and those which are connected in the reverse way. In the same way, if part of the turns of the moving coil be wound in one direction, and part in the other direction, the pressures developed in the two parts are opposite, and the effective pressure developed by the coil is equal to the difference of the pressures which are developed in the parts. If half the turns are right-handed and half left-handed, no current will flow in the coil when it moves in the magnetic field, because the pressure developed in one half of the turns tends to cause the current to flow one way, and the equal pressure developed in the other half of the turns tends to cause the current to flow in the opposite direction. The two tendencies neutralize each other, and no current flows.

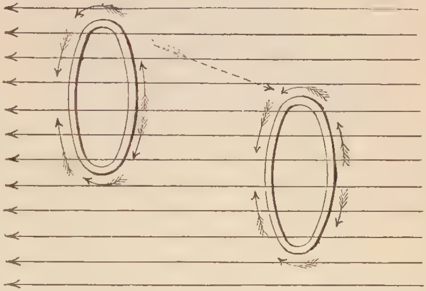

FIG. 71. — Coil moved parallel to itself in a Uniform Magnetic Field. The arrows show the directions of induced electrical pressures.

For the same reason, if *a coil of wire be moved straight across the lines of force* of a uniform field (Fig. 71), no current will flow in the coil, since the pressures developed in the two halves of each turn are in opposition, as shown by the arrows, and are of equal value. The truth of this may be easily proved by applying one of the rules given in the preceding article.

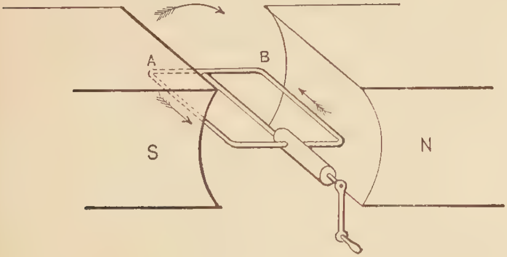

FIG. 72. — Coil revolved in Magnetic Field.

If the coil is mounted on an axis or shaft, so that it may be *revolved in the field* (Fig. 72), a different condition exists. Now, the two halves of the coil cut the lines of force in such a way that the pressures are in the same direction as shown by the arrows, and a current, therefore, flows in the coil. Figure 73 shows the coil after it has turned through a half revolution from its first position. From this figure it is seen that the two sides of the coil are now both cutting the lines of force in a direction which is opposite to that in which they cut the lines before. *The direction of the current in the coil is therefore reversed.* As the coil continues revolving, the current in it is reversed in every half revolution. Such a current, which flows first in one direction and then in another, is called an **Alternating Current.**

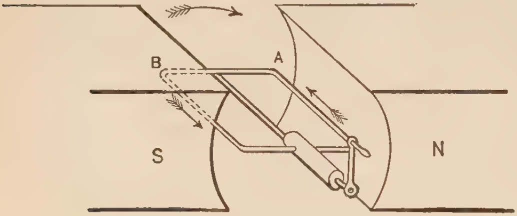

FIG. 73. — Coil revolved in Magnetic Field.

**137. Methods by which Pressures may be Induced.** — It has been experimentally proved that any change in the magnetic field around an electric conductor, which causes the lines of force to cut the conductor, tends to cause an electric current to flow in the conductor.[1] We are now sufficiently acquainted with the mutual effects of electric currents and magnetism, so that it is not surprising to learn that there are various conditions under which the effects of magnetism may result in an electric current. One of these conditions is seen where the motion of a conductor across magnetic lines of force causes a current to flow in the electric circuit, of which the conductor is a part. It is not necessary that the conductor move, but the magnetic field may move, so that its lines of force cut across stationary conductors. In fact, *an electric pressure is set up in a conductor when it cuts lines of force, whether the cutting be caused by the motion of the conductor, or by the motion of the lines of force.*

The magnetic lines of force which are cut by a conductor and so cause an electric pressure in the conductor may not come from a magnet, but may belong to an electric current in a neighboring wire. When a conductor is moved toward or away from a wire carrying a current, the lines of force belonging to the current are cut by the moving conductor and an electric pressure is induced in it. If the wire carrying the current is moved toward or away from the other conductor, the lines of force belonging to the current cut the conductor which is now stationary, and an electric pressure is set up as before.

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[1] Article 132.

The wire carrying the current may be in the form of a coil, like $P$ in Figure 74. An electric pressure may be set up in the conductors of another coil, S, by simply thrusting the first coil which carries a current into the second. After the **Primary** coil $P$ is pushed into the **Secondary** coil $S$ and its movement is stopped, the electric current in the secondary also stops because the conductors no longer cut lines of force and the electrical pressure is no longer produced. Now if the primary coil is drawn out from the secondary coil, an electrical pressure is again set up in the latter. *This pressure and its resulting current is opposite to that set up when the primary coil was pushed into the secondary, because the lines of force are cut in the opposite direction by the secondary coil.*

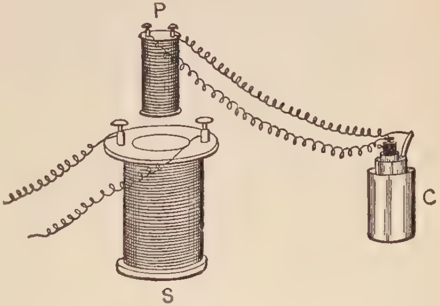

FIG. 74. — Primary and Secondary Coils for inducing a Current by moving Another Current.

The same effects may be produced by moving a secondary coil in and out of a larger primary coil, or by moving one coil around near the other. The battery cell $C$, shown in Figure 74, furnishes current to the coil.

## QUESTIONS

1. Give a brief history of the development of electromagnetic induction.

2. What seven men were most closely allied with the historical development of electromagnetic induction? What did they do?

3. How can a magnet be given a continuous motion by means of an electric current?

4. How can a wire bearing a current be arranged so that it will revolve continuously upon a magnet pole?

5. Why were not motors, made as in Question 4, useful in Faraday's day?

6. What facts led Faraday and Henry to believe that an electric current could be induced?

7. State Faraday's discovery with reference to a wire moving in a field. When was it made?

8. State the effect of any change of magnetic field about a wire. Who discovered this?

9. Describe Faraday's first dynamo. When did he make it?

10. What are magnetos?

11. Which is induced, the current or pressure?

12. What does an electromagnetically induced pressure depend upon primarily?

13. How many lines of force must be cut per second to create a pressure of 1 volt?

14. Suppose the rate of cutting lines was one hundred millions in 2 seconds, what would be the induced pressure?

15. Suppose the rate of cutting lines was one hundred millions in $\frac{1}{5}$ second, what would be the induced pressure?

16. Does Ohm's Law apply to circuits having a constant induced pressure?

17. Upon what three things does the number of lines cut by a conductor moving in a magnetic field depend?

18. With the slider and rail arrangement described in Article 134, how much more pressure will be induced if the original length of the slider be doubled? If the lines per square centimeter be doubled?

19. Upon what does the direction of an induced pressure depend?

20. Will the direction of an induced pressure be reversed by reversing the direction of movement? By reversing the field?

21. Will the induced pressure be reversed by reversing the directions of both the movement and the lines of force?

22. Does the current tend to flow away from or toward the point of high pressure in a conductor within which a current is being induced? How is it in the remainder of the circuit?

23. Is pressure used up within a conductor, having an induced pressure, by the induced current flowing through its resistance?

24. How can you show experimentally that part of the total pressure induced in a conductor is used in driving a current through its own resistance?

25. Compare the slider and rail arrangement with a pump and also with a battery.

26. Give the "hand" rule for determining the relative direction of motion, current, and lines of force.

27. Give the "swimming" rule for relative direction of motion, current, and lines of force.

28. Illustrate the fundamental laws of electromagnetic induction by a long swinging wire. Devise an illustration for yourself.

29. Illustrate, as in Question 28, by a magnet and coil of wire.

30. Why does increasing the number of turns in a coil increase the amount of pressure which is induced in it when a magnetic field is caused to thread the coil?

31. Why will a coil of wire moved across a uniform magnetic field not have a pressure induced within it?

32. What is an alternating current?

33. Why will a coil revolved in a magnetic field set up an alternating current?

34. Is it necessary that a conductor shall move to have a pressure induced within it?

35. May the magnetism set up by a current in a wire be made to induce a current in another circuit?

36. What happens when a coil carrying a current is pushed into another coil?

37. What happens when the inner coil of Question 36 is withdrawn?

**138. Mutual Induction.** — The effects described in Article 137 may be produced by fixing the coil $P$, inside of the coil $S$, and then varying the current which flows through the coil $P$. When the current increases in the primary coil, the lines of force belonging to the magnetic field of the current cut the conductors of the secondary coil as they are produced, and thus set up an electric pressure in the secondary coil *during the time the magnetic field is increasing.* If the **Primary Current** is reduced or shut off entirely, an electric pressure is set up in the secondary coils in the opposite direction *during the time that the magnetic field is decreasing.*

Electric currents which are set up in circuits by means of cutting lines of force are said to be caused by **Electromagnetic Induction**, and they are sometimes spoken of as **Induction Currents** or **Induced Currents**. The currents produced by dynamos are examples of currents induced by electromagnetic action. When the coils act directly upon each other, the effect is called **Mutual Induction.**

**139. Induction Coils.** — An appliance consisting of a primary coil and a secondary coil, which is used for the purpose of inducing currents in the circuit of the secondary coil by varying the current in the primary coil, is called an **Induction Coil**. The two windings of an induction coil are usually placed on an iron core, which greatly increases their effectiveness. The core must be made of iron wires, or currents will be induced in the core and thus heating and loss of power will result, since currents are induced in all closed circuits or masses of metal which are in a changing magnetic field. This division of the iron core of an induction coil is necessary for the same reason that it is necessary to laminate the iron cores of dynamo armatures, as will be described in a later chapter.

Each turn of the secondary windings of a well-built induction coil cuts practically all of the lines of force which are set up by the current in the primary coil, so that the total electrical pressure induced in the secondary windings may be controlled by winding the secondary coil with a greater or less number of turns of wire. In the induction coils made for scientific experiments, which are often called Ruhmkorff coils (Fig. 75), the secondary has so very many turns of extremely fine wire that the pressure produced in the secondary, when the current from a few battery cells is made and broken in the primary coil, may be so great as to cause an electric spark to jump a number of inches through air. In the induction coils commonly called **Transformers** or **Converters** (Fig. 76), which are common objects on the poles of electric light companies which use alternating currents, the secondary coils usually have fewer turns than the primary coils, and the electrical pressure induced in the secondary coils is therefore less than the pressure applied to the primary. Commercial transformers are usually enclosed in iron cases, but the illustration (Fig. 76) simply shows the coils and iron core which compose the essential parts of the device. Such trans-

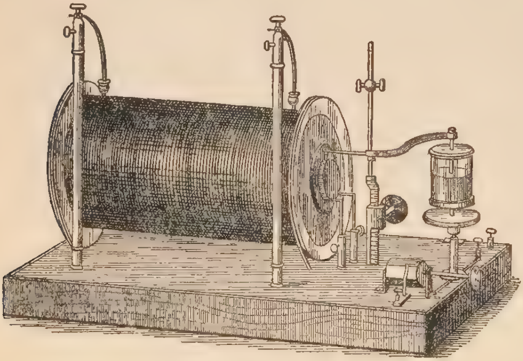
FIG. 75. — Ruhmkorff Coil.

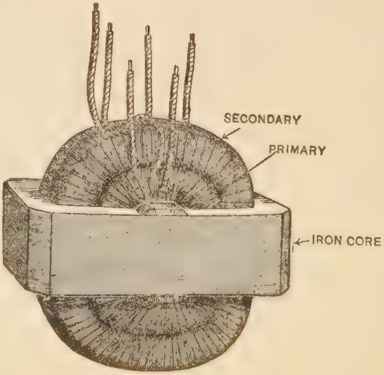

FIG. 76. — Alternating Current Transformer.

formers are used to reduce a high pressure which is used on the street circuits to a lower pressure which may safely and conveniently be used in buildings to operate electric lights. Transformers, as applied to electric lighting, will receive attention in a later chapter. By means of them we are able to perform the remarkable feat of commercially transferring electrical power from one circuit to another, although the circuits have absolutely *no electrical connection* with each other.

**140. General Rule for the Direction of Induced Pressures.** — If we remember the direction of the lines of force around a wire which carries a current[1] and the rule for determining the direction of an induced current,[2] it is easy to determine the direction of the current induced in any secondary circuit. By applying the rules referred to, the following rules relating to induced currents may be derived: —

1. *When a primary coil is* PUSHED INTO *a secondary coil, the secondary induced current is* OPPOSITE IN DIRECTION *to the primary current.*
2. *When a primary coil is* DRAWN OUT *of a secondary coil, the induced secondary current is in the* SAME DIRECTION *as the primary current.*

When the primary and secondary coils are fastened together and current is induced in the secondary by making and breaking the primary current, we have the following rules: —

3. *When the current is* MADE *(started) in the primary coil, a momentary* OPPOSITE OR INVERSE *current is induced in the secondary coil.*
4. *When a current is* BROKEN *(stopped) in the primary coil, a momentary current of the* SAME DIRECTION *is induced in the secondary coil.*

These rules relate to the flow of current when the secondary circuit is closed. If the secondary circuit is open, the electrical pressure which is set up is in such a direction that the current would flow in the direction indicated were the circuit closed.

**141. Lenz's Law.** — A careful examination of these rules shows a very important fact which may be stated in this way: *The direction of an induced current is always such that the magnetic field belonging to it tends to oppose the change in the strength of the magnetic field belonging to the primary current.* For instance, when the primary current of an induction coil is "made," an inverse current is induced in the secondary coil whose magnetic field opposes the growth of the magnetic field of the primary current. When the primary circuit is broken, the magnetic field of the induced current opposes the decay of the magnetic field belonging to the primary current. Another illustration may be taken from the primary coil which is pushed into a secondary coil. When the primary coil carrying a current is pushed into the secondary, an *inverse current* is induced which sets up a magnetic field which tends to repel the primary coil and, therefore, *opposes its motion*. When the primary coil is drawn out of the secondary, the *direct induced current* sets up a magnetic field which tends to attract the primary coil and, therefore, again *opposes its motion*.

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[1] Article 122.

[2] Article 135.

In the case of a dynamo, the current which is induced in the armature conductors has such a direction that its magnetic effect tends to stop the motion of the armature; and to keep it rotating, mechanical power must be applied to the armature in proportion to the amount of power represented by the currents generated.

The above facts may be briefly stated in one sentence. *When electric currents are induced by a changing magnetic field, the magnetic field belonging to the induced currents tends to stop the change in the original field.* We have also the following statement which results directly from the former. *When electric currents are induced by the motion of a conductor, the induced currents have such a direction that their magnetic effect tends to stop the motion.* This is called Lenz's Law, after a German scientist who first formally stated the principle.

The principles stated in the preceding paragraph are a direct result of the general law of the Conservation of Energy.[1] We can transform mechanical energy into electrical energy or *vice versa;* or, we can transform the energy of electrical currents flowing under one pressure into the energy of electrical currents flowing under another pressure; but in every case as much energy must be put into the transforming apparatus — whether it be dynamo, motor, Ruhmkorff coil, or transformer — as is taken out. We have already seen that the useful "output" of electrical apparatus is usually smaller than the "input" by a certain percentage of the total energy which has been changed into useless heat.

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[1] Article 111.

## PROBLEMS

*A.* A coil, containing an iron core, has 500,000 lines passing through it. When this coil is pushed into another coil of 100 turns at a fixed speed an average pressure of 5 volts is induced. How many turns must the secondary coil have in order that the induced pressure may be 100 volts? *Ans.* 2000 turns.

*B.* In an induction coil having 2000 turns on the secondary the average alternating pressure induced is 500 volts. How many turns must the secondary have in order that 100, 1000, and 10,000 volts may be induced? *Ans.* 400, 4000, 40,000 turns.

*C.* If work equal to 30 watts for one second is transferred from a primary coil to a secondary coil while the former is being pushed into the latter as described in Example *A*, how many foot pounds of work must be expended in pushing the primary coil, provided that no appreciable losses occur in the transformation? (Aid: Apply the law of the conservation of energy.) *Ans.* 22.1 (approx.).

*D.* If 100 watts are obtained from the secondary coil of a transformer, how many watts must be put into the primary, supposing the losses of transformation equal 10 per cent of the input? *Ans.* 111 watts (approx.).

**142. Self-induced Pressures.** — A varying current may have an inductive effect upon the coil in which it flows itself, in addition to its inductive effect upon adjacent conductors. When a current is started in a coil it sets up a magnetic field which quickly grows from zero to its full value. As the field grows, its lines of force cut the turns of the coil and induce in them an electric pressure which opposes the growth of the current. On stopping the original current, its magnetic field quickly dies away and the lines of force again cut the turns of the coil, but this time in such a direction that the self-induced electric pressure upholds the original current. If the coil has a great many turns wound on an iron core, its **Self-induction** may be of sufficient magnitude to make a brilliant spark or give a severe shock when the circuit is broken. The spark at breaking a circuit is often spoken of as caused by the *extra current of self-induction.* The effect of self-induction is made use of in so-called **Spark Coils**, which are used with devices for lighting gas by electricity, and which consist simply of a coil containing many turns of insulated wire wound on a core of iron wire. The effect of self-induction makes itself evident if the circuit of a single battery cell is broken between the hands when the circuit contains a spark coil, telegraph instrument, or other electromagnetic coil.

**143. Mutual Attraction or Repulsion of Electric Circuits.** — The fact that a conductor carrying an electric current is always surrounded by a magnetic field[1] would lead us to expect conductors carrying electric currents to attract and repel each other. This is indeed the fact. We have already seen that solenoids act towards each other exactly as though they were magnets.[2] In every case we have learned that, where magnets or solenoids are brought into each other's influence, they tend to move so that their lines of force shall be placed parallel and in the same direction. Exactly the same is true of straight or curved wires which are brought into each other's influence. Remembering this, we can see that *two wires lying side by side must attract each other if they carry currents flowing in the same direction.* This is because the lines of force can only become parallel and of the same direction when the two conductors are very close together. *When the currents flow in opposite directions the wires repel each other.* In the same way, if the wires are inclined to each other they tend to turn around into such a position that the wires are parallel and the currents flow in the same direction (Fig. 77). This principle is used in the design of electrical measuring instruments, such as are described amongst others in Chapters XI and XIII.

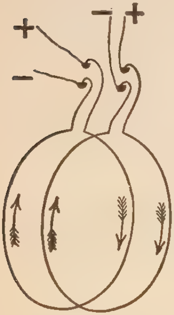

FIG. 77. — Parallel Wires carrying Currents.

## QUESTIONS

38. How can an induced pressure be set up without any mechanical movement?

39. When the current is made and broken in a primary coil, what are the relative directions of the currents induced in the secondary?

40. If the current has a steady value in the primary coil, will a pressure be induced in the secondary?

41. What is mutual induction?

42. What are induced currents or pressures called?

43. What is an induction coil?

44. Why is an iron core used in an induction coil?

45. Why is the core of an induction coil not made of solid iron?

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[1] Chapter IX.

[2] Article 124.

46. What is a Ruhmkorff coil?

47. What is a transformer?

48. How can a high or low pressure be obtained by means of induction coils?

49. Give the two rules showing the relative directions of the induced and inducing currents in movable primary and secondary coils.

50. Give the rules as in Question 49 when the two coils are fixed.

51. If a primary coil carrying a current is pushed into the secondary, will the induced current be in the same direction as if the coil was first pushed in and the primary current was then started?

52. What is Lenz's Law?

53. Illustrate the application of Lenz's Law to a pair of movable and a pair of mutually fixed induction coils.

54. If a conductor forming part of a circuit is taken in the hand and cut rapidly across the field of a strong electromagnet, what will happen? Why?

55. In what way does Lenz's Law follow from the law of the conservation of energy?

56. Will more energy be put into the primary coil of an induction coil when the secondary is closed than when it is open? Why?

57. Does it take more work to thrust a coil carrying a current into another when the latter is connected to a closed circuit, than if its circuit is open?

58. What is a self-induced pressure?

59. Why is there an extra current of self-induction when a circuit is broken?

60. What is a spark coil?

61. When a current is building up, does the self-inducted pressure aid or impede the original current? How is it when a circuit is broken?

62. Does Lenz's Law apply to cases of self-induction?

63. Do currents which flow in the same direction in adjacent wires repel each other? Do they attract each other?

64. Do currents which flow in opposite directions in adjacent wires repel each other?

# CHAPTER XI

## GALVANOMETERS AND VOLTAMETERS

**144. Galvanometers.** — Instruments for detecting and measuring electric currents, the indications of which are dependent upon the deflection of a magnetic needle caused by the magnetic effect of the current flowing in a coil which surrounds the needle, are called **Galvanometers.** These instruments are made in a great variety of forms, and are widely used for measurements in shops and laboratories.

In most forms of galvanometers the magnetic needle is placed at the centre of a coil of wire. This coil may have a great number of turns of fine wire, in which case the galvanometer is "sensitive," — that is, the needle is appreciably deflected by a very small current; or the coil may have but few turns of thick wire, in which case the galvanometer is intended for use with comparatively large currents. In some cases the coil of the galvanometer is placed so that it stands in an exact north and south position (that is, in the magnetic meridian) like the needle. The magnetic force due to the coil, which is at right angles to its wire,[1] is then at right angles to the magnetic force of the earth and also to the length of the needle. When the coil is in this position, a current in the coil exerts its greatest force to deflect the needle.

When a galvanometer is connected in a circuit, the presence of a current is shown by the deflection of the needle. The direction of the current is shown by the side toward which the north pole of the needle moves.[2] The strength of the current is indicated by the amount of the needle's deflection, since the position which the needle takes depends upon the relative magnitude of the magnetic forces due to the current and the earth.[3] The earth's magnetism may be considered to be approximately constant at any fixed position.

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[1] Article 121.

[2] Article 122.

[3] Article 120.

**145. Tangent Galvanometer.** — When the diameter of the galvanometer coil is very great compared with the length of the needle, the trigonometrical tangents of the angles through which the needle is deflected by various currents are proportional to the currents. Such a galvanometer is called a **Tangent Galvanometer** (Fig. 78). Other galvanometers in which the coil is moved so as to bring the needle back to zero (Fig. 79), are called **Sine Galvanometers**, because the trigonometrical sine of the angle through which the coil is moved is proportional to the current causing the deflection. In some rough galvanometers a pointer is attached to the needle, and the deflection is read off on a divided circle, over which the pointer moves. The circle of such a galvanometer is usually divided uniformly in degrees.

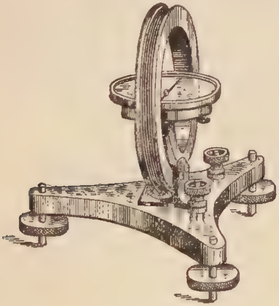
FIG. 78. — Tangent Galvanometer.

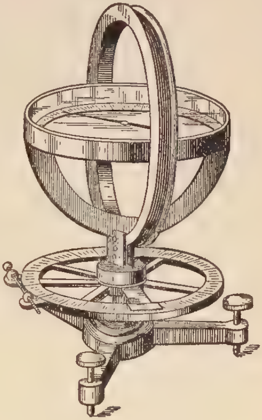
FIG. 79. — Sine Galvanometer.

**146. Reflecting Galvanometers.** — For exact measurements, so rough a method of reading deflections is not sufficiently accurate, and **Reflecting Galvanometers** are used (Fig. 80). A small mirror is attached to the magnet in these, and the deflections are read off by means of a small telescope through which a reflection of a stationary scale is seen in the mirror. When the needle moves, the mirror moves with it, and the reflection of the scale as seen in the telescope appears also to move and the deflection of the needle is thus determined. Instead of using a telescope and scale, as is usually done in America, a lamp and scale (Fig. 81), may be used. In this case a beam of light from a lamp which is placed behind a slit in front of the galvanometer is reflected by the mirror upon a scale, where it shows as a spot of light. When the needle with its mirror is deflected, the spot of light moves along the scale, thus showing the magnitude of the deflection. This is a very convenient arrangement to use when testing must be done in dark rooms or vaults, but it cannot be used in a light place.

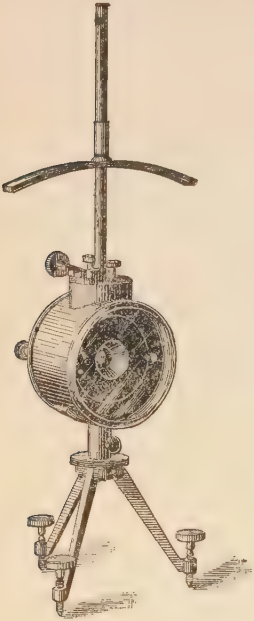

FIG. 80. — Reflecting Galvanometer.

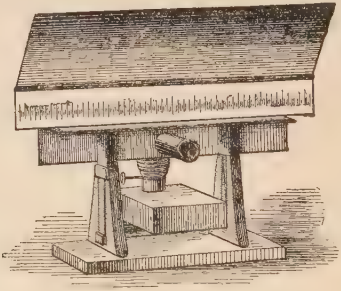

FIG. 81. — Lamp Stand and Scale.

**147. Needle Supports.** — The support of the needle is sometimes on a finely wrought pivot, and the needle is then set with an agate or ruby centre so that it may move easily. The friction of the finest pivot, however, is so great that it destroys the sensitiveness of a fine galvanometer, so that in all fine galvanometers the needles are suspended by means of a **Fibre** which is usually made of *unspun cocoon silk*. This fibre must be strong enough to support the weight of the needle with its mirror, but it should be as fine as possible, so that it will not oppose the least force against the deflection of the needle. The needle and mirror are usually made as light as possible and the suspending fibre is sometimes so fine that it can scarcely be seen. The length of the **Suspension** varies from a small fraction of an inch to many inches. Fibres are now often made from very fine hairs of quartz, which has been melted in a blowpipe flame and drawn out.

**148. Controlling Magnets.** — It is often convenient to make the needle of a galvanometer independent of the direction of the earth's magnetism or to vary the strength of the **Directive Force**, that is, the force which holds the needle in the magnetic meridian. For this purpose galvanometers are generally arranged with one or more **Directive Magnets** or **Controlling Magnets.** One is shown as a curved bar placed on a stem above the galvanometer of Figure 80. By varying the position of the magnet with respect to the needle, the position of rest taken by the needle may be controlled as desired, and the galvanometer may be set in any desired position.

**149. Astatic Needles.** — In order that a galvanometer may be made very sensitive, it is desirable to make the controlling force very weak, — in some cases much weaker than that due to the earth's magnetism. Consequently the effect of the earth's magnetism must be overcome. For this purpose what are known as **Astatic Needles** are used. These consist of a pair of needles of practically equal size and magnetic strength which are fastened to a light thin wire, one above the other, so that their north poles point in exactly opposite directions. It is usual to arrange a coil of wire for each needle, so that the galvanometer has two coils, and the mirror may be fastened to any convenient part of the supporting wire (Fig. 82). In some very sensitive galvanometers there are eight needles arranged **Astatically,** and eight coils.

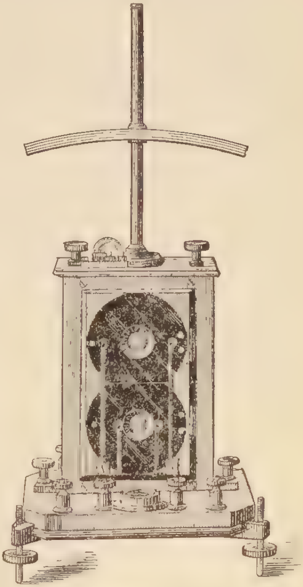

FIG. 82. — Astatic Reflecting Galvanometer, with Two Coils.

**150. Forms of Needles.** — The forms in which galvanometer needles are made are quite various. Some needles are in the form of a partially split bell, one side being the north pole and the other being the south pole. Other needles are made of flat disks or rings which are so magnetized that a portion of the edge serves as the north pole and the opposite portion as the south pole. The commonest form of needle is one built up of several little magnets, made from a watch spring, which are laid side by side with the poles all the same way. These are usually fastened to the back of the galvanometer mirror or to a little disk of aluminum, as shown in Fig. 82*a*, where *c*, *c*, *c*, are the little magnets and *A* is the suspension.

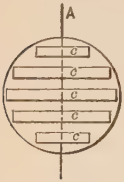

FIG. 82*a*. — Galvanometer Needle, composed of Several Small Magnets cemented to a Disk.

**151. D'Arsonval Galvanometer.** — A very convenient form of galvanometer is one in which the coil is suspended so as to move in the magnetic field of a strong horseshoe magnet (Fig. 83). In this instrument the relations of coil and magnet are practically the reverse of those in the common galvanometers. This is called a **D'Arsonval Galvanometer**, after a French scientist who put it into useful form. The suspension of the coil of a D'Arsonval galvanometer must be arranged so that the current may get into and out of the coil. The coil is, therefore, often supported between stretched phosphor-bronze wires which are connected to it at the top and bottom and which serve as leads for the current. Sometimes the coil is suspended on a silver wire by means of which the current can enter the coil, and a wire at the bottom of the coil dips into a bottle of mercury so that the current can get out.

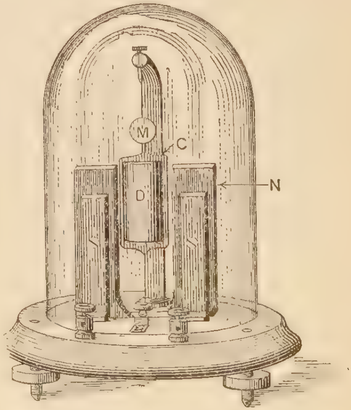

FIG. 83. — D'Arsonval Galvanometer. *M*, mirror; *C*, coil; *N*, magnet; *D*, stationary soft iron core.

**152. Dead-beat Galvanometer.** — One reason that a D'Arsonval galvanometer is convenient for general use is, because it is **Dead-beat**; that is, when the coil is deflected it goes at once to its position without a tedious period of swinging back and forth. Ordinary galvanometers may be made more or less dead-beat by surrounding the needle with a ball of copper, or by attaching to the suspension fibre small wings of mica or aluminum, which are enclosed in a small chamber.

**153. Galvanometer Constant.** — In order that a galvanometer may be used to actually measure electric currents in amperes, the **Constant of the Galvanometer** must be known, or the galvanometer must be **Calibrated or Standardized.**

When the deflections of a galvanometer bear some fixed relation to the currents causing the deflections, it is said to have a **Constant.** For instance, in the case of a tangent galvanometer, the current which causes a certain deflection of the needle is given in amperes by multiplying the tangent of the angle of deflection by the constant of the galvanometer. The constant of a tangent galvanometer may be directly calculated when the coil is circular, and its diameter and number of turns and the strength of the earth's magnetism are known. The constant may also be determined by passing a current of known strength through the galvanometer and observing the deflection. The needle of a reflecting galvanometer moves through so small an arc that the deflection may frequently be taken to be proportional to the current; this is almost always the case with D'Arsonval galvanometers. *The constant*, under such circumstances, *is the amount of current required to cause a deflection of one scale division.* The constant is also sometimes defined as the number of divisions of the deflection caused by a certain battery when acting through a resistance of one megohm.

When the deflections of the galvanometer are not known to bear a fixed relation to the currents causing them, the galvanometer must be experimentally calibrated. That is, currents of various known strengths must be passed through the galvanometer and the deflections observed. These observations may be set

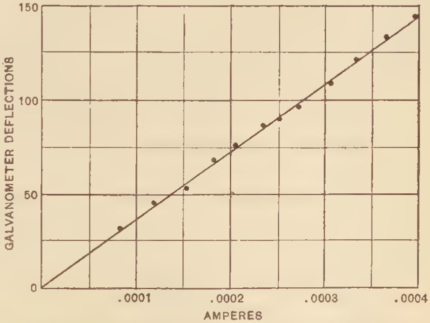

FIG. 84. — Calibration Curve of a Galvanometer.

down in a table, so as to be used in future work with the galvanometer, or the observations may be platted in a curve on cross-ruled paper. Such a **Calibration Curve** is often convenient, since the value of a current corresponding to any deflection may be at once determined from it. A calibration curve is illustrated in Figure 84.

When galvanometers are used simply for the detection of currents, or for comparing the relative magnitudes of currents, as is frequently the case, calibration is unnecessary.

### PROBLEMS

*A.* A deflection of 200 divisions is caused by sending .001 of an ampere through a reflecting galvanometer. If the deflections are proportional to the current, what is the galvanometer constant? *Ans.* .000005 of an ampere.

*B.* A reflecting galvanometer and resistance box in series have a total resistance of 100,000 ohms. One volt pressure causes a deflection of 100 divisions on the galvanometer scale. If the deflections are proportional to the current, what is the constant of the galvanometer? *Ans.* .0000001 of an ampere.

*C.* A certain current causes a deflection of 100 divisions on a galvanometer scale. If the constant of the galvanometer is .0001, what is the current? *Ans.* .01 of an ampere.

*D.* The total resistance of a circuit containing a galvanometer is 1000 ohms. The constant of the galvanometer is .0001. If the galvanometer is deflected 100 divisions, what pressure is impressed upon the terminals of the circuit? *Ans.* 10 volts.

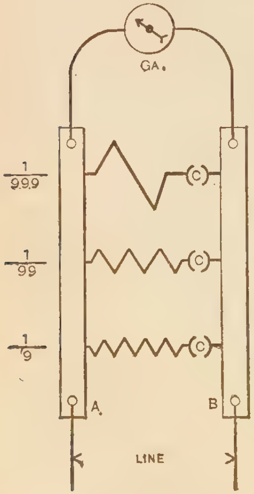

FIG. 85.—Galvanometer and Shunt.

**154. Galvanometer Shunts.**—It is often desirable to be able to use a sensitive galvanometer for reasonably rough measurements, and thus avoid the duplication of expensive instruments. For this purpose the galvanometer may be **Shunted**,[1] by connecting any desired resistance across the terminals (Fig. 85) in such a way that the current of the circuit will divide between the galvanometer coils and the **Shunt**. As a rule, it is desired to make this division of current in some even ratio, as 1 : 9, 1 : 99, 1 : 999, etc., and then the resistance of the shunt must bear the proper ratio to the resistance of the galvanometer windings. Suppose it is desired to make a shunt of such resistance that its use will cause exactly one-tenth of the total current to flow through the galvanometer, then nine-tenths of the current will flow through the shunt. By the laws of divided circuits[1] the resistance of the shunt must be one-ninth of the resistance of the galvanometer. When the resistance of the shunt is one ninety-ninth of the resistance of the galvanometer, one-hundredth of the current will flow through the latter; and when the shunt resistance is one nine-hundred-ninety-ninth ($\frac{1}{999}$) of the galvanometer resistance, one-thousandth of the current will flow through the latter.

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[1] Article 105.

Galvanometers usually have corresponding shunt boxes sold with them, which have three coils, respectively marked $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$. When the shunt box is connected in parallel with the galvanometer, either of these shunts may be placed in the circuit by means of a plug, or the shunt circuit may be entirely broken. When a shunt is plugged into the circuit, $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ part of the whole current flows through the galvanometer, depending upon the position of the plug. Figure 86 shows a common form of shunt box, and Figure 85 shows the connections of the galvanometer and shunt box. When the plug is inserted in either of the holes marked *C*, the corresponding shunt is connected in the circuit.

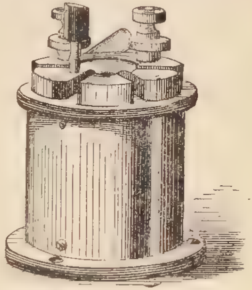

FIG. 86. — Exterior of Shunt Box.

## PROBLEMS

*A.* A galvanometer has a resistance of 1200 ohms; it is desired to shunt it so that only .001 of the total current to be measured will pass through it. What must be the resistance of the shunt? *Ans.* 1.2012 ohms (approx.).

*B.* A galvanometer, in which the deflections are proportional to the current, is deflected 100 scale divisions by 1 milliampere. What is the strength of a current which causes a deflection of 150 divisions, when the galvanometer is shunted by a $\frac{1}{99}$ shunt? *Ans.* 150 milliamperes.

*C.* A galvanometer, having a constant of .00005 of an ampere per division, shows a reading of 200 divisions when shunted by a $\frac{1}{999}$ shunt box. What current is flowing? *Ans.* 10 amperes.

[1] Article 103.

*D.* A deflection of 20 divisions is caused by sending .001 of an ampere through a reflecting galvanometer, which is shunted by a $\frac{1}{9}$ box. If the deflections are proportional to the current, what is the galvanometer constant? *Ans.* .000005 of an ampere.

**155. Voltameter.** — An instrument for measuring currents by means of their electrochemical action, which is often used in calibrating galvanometers, is called a **Voltameter.** We have already seen that chemical action goes on in a battery cell or electrolytic vat,[1] when a current is passed in either direction through the cell, and that the amount of the action is proportional to the number of coulombs of electricity passed through the cell. The chemical action in a voltameter is similar to that which takes place in a voltaic cell, but both plates are of the same material, and there is, therefore, no tendency to set up a current due to the direct action of the cell.[2]

**156. Water Voltameter.** — The earliest form of voltameter is one in which sulphuric acid, greatly diluted by water, is electrolyzed.[3] This is called a **Water Voltameter.** A form of water voltameter is shown in Figure 30. When this is to be used, diluted acid is poured into the funnel *C*, at the back, and rises to the top of the two arms, *AB*, in front, if the stopcocks at their tops are open. After the tubes are filled the cocks are closed, and the current is passed between the platinum electrodes, *EE*. The electrochemical action set up by the current causes oxygen to go to the positive pole or anode, and hydrogen to go to the negative pole or cathode. The gases rise in the tubes above their respective electrodes and displace the water. The direct action of the current causes a decomposition of the sulphuric acid in the water, but additional chemical action is set up by the decomposed sulphuric acid, which makes the total action equivalent to the decomposition of water.

Water is composed by bulk of two parts of hydrogen to one part of oxygen, and consequently the tube over the cathode collects twice as much gas as that over the anode.[4] If a steady current is passed through such a voltameter for a given number of seconds, the strength of the current can be determined from the amount of gases collected per second. For, the number of coulombs of electricity passed through the voltameter is determined from the amount of the gases collected and their electrochemical equivalent.[1] *The number of coulombs passed through the circuit per second is equal to the current in amperes.*

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[1] Chapters IV and V.

[2] Chapter V.

[3] See Articles 61 and 66.

[4] Article 66.

**157. Metal Voltameter.** — A water voltameter is not a very convenient or satisfactory instrument, and voltameters in which the electrolytes are solutions of the salts of metals are preferred for actual measurements. When such a solution is **Electrolyzed** between plates of the metal contained in the solution, the solution is decomposed; *the metal from the solution goes with the current to the cathode* where it is deposited, and *the acid part of the compound goes to the anode*, which it attacks, and with the metal forms a new portion of the compound, which is dissolved in the solution. The cathode should, therefore, be expected to gain exactly as much metal from the deposit as the anode loses by the attack of the acid.

This would be true if no chemical action occurred except that directly caused by the current. It is a fact, however, that the character of a deposited metal often varies with the strength of the current by means of which it is deposited, or with the strength of the solution used as the electrolyte. Copper is sometimes deposited in the form of a black powder instead of a smooth, bright layer of metal. Silver is often deposited in crystals which build across the electrolyte between the electrodes. Tin forms a "tree" of tin crystals, when deposited from a tin chloride solution, the branches of which spread out from the electrode through the solution. The greatest care must, therefore, be used to get satisfactory measurements. The direction of the current should be determined by a compass needle before the voltameter is placed in the circuit.

The loss of the anode is seldom as reliable a measure of the current as the gain of the cathode, because bits of metal are liable to be loosened from the former and fall off, and the anode also often suffers from oxidation.

**158. Silver Voltameter.** — When a **Silver Voltameter** is used for the measurement of a current, as is assumed in the definition of the ampere,[2] the electrolyte is a solution of the **Nitrate of Silver** of fixed strength. The cathode is usually a platinum bowl upon which the silver is deposited, and the anode is a wire or plate of pure silver, which is wrapped in filter paper to keep bits of silver from dropping on to the cathode. Before a measurement of current is to be made, the cathode is very accurately weighed, the solution is then poured into it and the anode is put in place. The current is turned on and continued for a desirable number of seconds. It is then stopped, the cathode is carefully washed and dried, and finally again weighed with great care. From its gain in weight, the time the current flowed, and the electrochemical equivalent of silver, the value of the current is determined.

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[1] Articles 62 and 65.

[2] Article 96.

**159. Copper and Zinc Voltameters.**— On account of the expense of the silver consumed and the care required in using a silver voltameter, it is not satisfactory for measuring currents exceeding about one ampere. For larger currents, a voltameter having *copper plates*, and a *solution of copper sulphate* for electrolyte, is generally used. A good deposit is usually obtained if the copper solution has a density between 1.10 and 1.18, as measured by a hydrometer. The action of the solution is improved by the addition of a small amount of sulphuric acid.

The meter formerly used almost exclusively by Edison electric lighting companies to determine the quantity of electricity delivered per month to customers, consists of a shunted voltameter with amalgamated zinc plates and an electrolyte of zinc sulphate.

The weight in grammes of different metals deposited by one ampere in one second (that is, the electrochemical equivalents) is given in a table contained in Chapter V. The following data, taken from that table, give the grammes of the gas or metal which may be deposited for each coulomb passed through either of the voltameters just described:—

| METAL | ELECTROCHEMICAL EQUIVALENT |
|---|---|
| Hydrogen, | .0000104 |
| Silver, | .001118 |
| Copper, | .000329 |
| Zinc, | .000338 |

One gramme (metric measure) is equal to 15.432 grains, or approximately thirty-five one-thousandths of an ounce.

## PROBLEMS

*A.* How much weight in grammes would the cathode of a silver voltameter gain if a current of exactly 1 ampere flowed through it for 1 hour? *Ans.* 4.025 (approx.).

*B.* A current flowing through a copper voltameter for 100 minutes increased the weight of the cathode 10 grammes. What was the average current flowing? *Ans.* 5.07 amperes (approx.).

*C.* An Edison zinc voltameter, after being on a house-lighting circuit for a month, was found to have deposited 15.43 grains of zinc upon the cathode. How many ampere hours (an ampere hour is an ampere flowing for an hour) had been consumed during the month in lighting the house if $\frac{1}{975}$th of the total current passed through the meter? *Ans.* 801 (approx.).

## QUESTIONS

1. What is a galvanometer?
2. What is a sensitive galvanometer?
3. Why are a large number of turns used in galvanometers for measuring small currents, and a small number of turns in galvanometers for large currents?
4. Why is it desirable to have the resistances of galvanometers for measuring large currents very low?
5. Why does a galvanometer coil act with the greatest force upon its needle when the coil stands in a north and south plane?
6. How can the direction of a current be found by a galvanometer? Its strength?
7. What is a tangent galvanometer?
8. What is a sine galvanometer?
9. What is a reflecting galvanometer?
10. Explain the use of the lamp, telescope, and scale in a reflecting galvanometer.
11. How are galvanometer needles suspended or supported?
12. What is a "directive magnet"? How is it used?
13. What are astatic needles?
14. Why are astatic needles used in galvanometers?
15. How are galvanometer needles made?
16. What is a D'Arsonval galvanometer?
17. How are D'Arsonval galvanometer coils supported?
18. Give two advantages in favor of D'Arsonval galvanometers.
19. What is a "dead-beat" galvanometer?
20. How are galvanometers made dead-beat?
21. What is a galvanometer constant?
22. What is a galvanometer calibration curve?
23. How can a galvanometer calibration curve be obtained?

24. If the deflections of a galvanometer were directly proportional to the currents, how could the relative strengths of two currents be found?

25. What is a galvanometer shunt?

26. If it is desired that one-thousandth part of a current to be measured shall flow through a galvanometer, what ratio must the resistance of the shunt bear to that of the galvanometer? Why?

27. How can a sensitive galvanometer be used for measuring large currents?

28. What is a voltameter?

29. How can a current be measured by means of a water voltameter?

30. Describe the action in a metal voltameter.

31. What is likely to happen in copper, silver, and tin voltameters if the current is too strong, or the strength of the solution is not right?

32. How can a current be measured by a metal voltameter?

33. In measuring the current by a metal voltameter, should the change in the weight of the anode or of the cathode be used? Why?

34. What is a silver voltameter? How is it used?

35. What electrolyte is used in a silver voltameter for determining the international ampere?

36. Tell how you would measure currents by copper and zinc voltameters.

37. What is the numerical value of the electrochemical equivalent of silver?

# CHAPTER XII

## MEASUREMENT OF ELECTRICAL RESISTANCE

**160. Measurement of Resistance by Substitution.** — All useful methods of measuring electrical resistance depend directly upon the indications of Ohm's Law. The simplest method of measuring a resistance is by what is called **Substitution.** The resistance to be measured is connected in series with a galvanometer and a constant battery,[1] and the deflection of the galvanometer is noted. Then the unknown resistance is removed from the circuit, and a **Variable Resistance Box** or **Rheostat** (Fig. 87) is substituted for it. The resistance of the resistance box is then adjusted until the galvanometer deflection is the same as before.

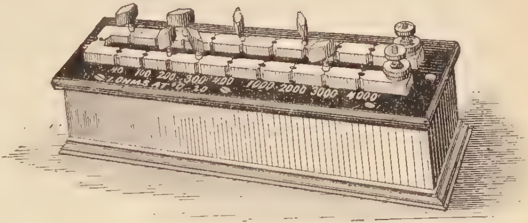

FIG. 87. — Variable Resistance Box.

The resistance inserted in the circuit by means of the box is equal to the unknown resistance, because the galvanometer shows that the same amount of current flows through the circuit in the two cases, and the total electrical pressure acting in the circuit is the same in each case, and consequently, according to Ohm's Law, the resistance of the total circuit must be the same in the two cases. It is necessary that no changes be made in the circuit during the process besides the substitution of the variable known resistance for the unknown one.

**161. Resistance Boxes.** — Resistance boxes of the character referred to in the last article are generally boxes containing spools of silk-covered wire, each of known resistance, which may be used in electrical measurements. German silver or some similar alloy, having a comparatively low conductivity and a small temperature coefficient,[1] is generally used in making the spools or coils for resistance boxes. In making the coils, the proper length of wire for each is taken and doubled at the middle, and it is then wound double upon a spool. The object of doubling the wire is to avoid the effects due to self-inductance, which will be explained later. After the spools are wound, they are dipped in paraffine, and then placed inside the box, and fastened to the under side of the top of the box by brass bolts (Fig. 88), which also fasten a series of brass blocks to the upper side of the top, as is illustrated in Figure 87. The individual ends of each coil are connected to adjoining brass blocks, so that all the coils are in series when the blocks are not directly connected together. This is shown in Figure 89, where the ends *a* and *b* of one of the resistance coils are fastened to the brass blocks *L* and *M*, while the ends *c* and *d* of the next coil are fastened to the blocks *M* and *N*. The brass blocks are so arranged that they may be connected together by plugs which fit in tapering holes, as shown in the figure, thus "short-circuiting" the coils.

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[1] Article 42.

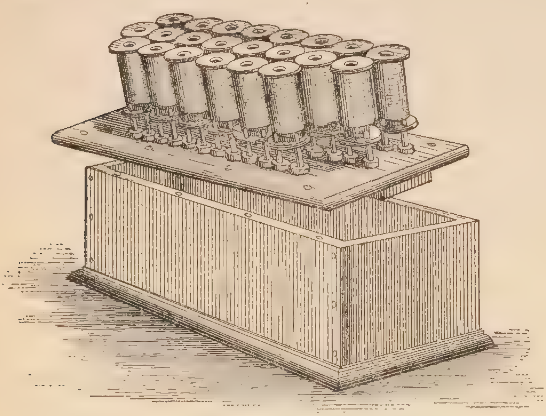

FIG. 88.—Spools of Wire fastened to Under Side of Cover of Resistance Box.

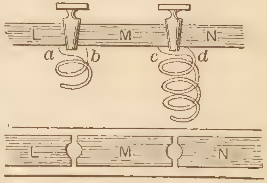

FIG. 89.—Arrangement of Brass Blocks and Plugs for Resistance Box.

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[1] Articles 91 and 98.

If such a resistance box is connected in a circuit when all the plugs are removed, the current flows through all the resistance coils in series. If one of the plugs is inserted in a hole, the corresponding resistance coil is **Short-circuited**, that is, a negligibly small resistance (that of the plug) is connected in parallel with it, and no appreciable current flows through the coil. Since the resistance of the plug is practically negligible, the resistance of the circuit is reduced, when the plug is inserted, by the amount of the resistance of the corresponding coil. The resistance of a box may, therefore, be varied at will by simply inserting or removing plugs.

Resistance boxes generally have a series of coils of different resistances, usually given in tenths, units, tens, hundreds, etc., of ohms. The final adjustment by the manufacturer of the coils of a fine resistance box, so that they may all have the right resistance, is a matter requiring great care. It is effected by soldering more or less of the doubled ends of the wire together after the spool is mounted in its box. In order that the adjustment may be made in this way it is necessary that the resistance of the coil when wound on the spool shall be a little greater than the desired final value. Great care must be taken when adjusting coils to avoid errors due to the temperature of the coil changing, since the wires are likely to become heated by the soldering.

**162. Wheatstone Bridge.** — The measurements for determining the exact value of the coils are made by what is called a **Wheatstone Bridge,** after Wheatstone, an English scientist and inventor. This consists of an arrangement of resistance coils which are used in a combination with a battery and galvanometer, as shown diagrammatically in Figure 90. In the figure, $A$, $B$, and $R$ represent resistance boxes with coils of known resistance; $X$ is the resistance to be measured; $F$ and $G$ are a battery and a galvanometer; $K_1$ and $K_2$ are **Keys** placed in the circuits with the battery and galvanometer, by means of which the circuits may be made and broken; $M$, $N$, $O$, and $P$ are points where the various **Bridge Circuits** are connected together.

**163. Measurement of Resistance by Wheatstone Bridge.** — From an application of the law of the fall of potential along a resistance as deduced from Ohm's Law,[1] it is easy to see how the resistance of the coil $X$ is determined by this device. Suppose the **Battery Key** $K_1$ (Fig. 90) is depressed, then the current flows from the battery through the key to the point $P$. Here it divides, and part goes to $O$ by way of $M$, and the other part by way of $N$. From $O$ the current returns to the battery. The points $P$ and $O$ are at a certain difference of electrical pressure (which we call $E$) that depends upon the battery, and the fall of pressure from $P$ to $O$ by way of either $M$ or $N$ is equal to $E$. The fall of pressure between $P$ and $M$ is (according to the law that the fall of pressure is proportional to the resistance passed over) $E\frac{x}{x+b}$ where $x$ and $b$ represent the resistance of the branches of the bridge $X$ and $B$ respectively. In the same way the fall of pressure between $P$ and $N$ is equal to $E\frac{r}{r+a},$ where $r$ and $a$ represent the resistances of $R$ and $A$.

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[1] Article 106.

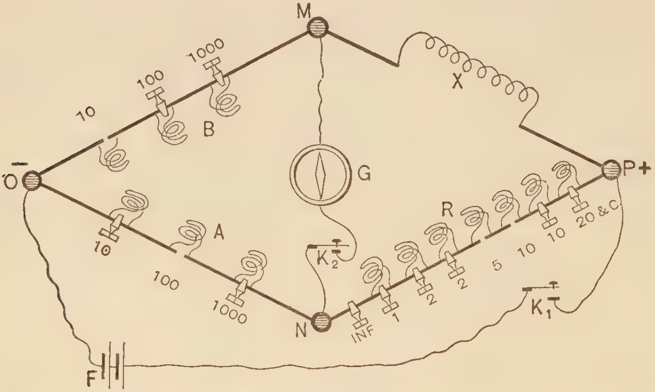

FIG. 90.—Diagrammatic Illustration of Wheatstone Bridge and its Connections.

If the fall of pressure between $P$ and $M$ is greater than that between $P$ and $N$ the point $M$ is at a lower pressure than $N$, and if the **Galvanometer Key** $K_2$ is depressed, a current will flow from $N$ to $M$ through the galvanometer, deflecting the needle. Now, if the resistance $r$ is increased until the fall of pressure between $P$ and $N$ is the greater, a current will flow from $M$ to $N$ when the galvanometer key is depressed, and the needle will be deflected in the opposite direction.

Finally, if the resistance of $r$ is so adjusted by arranging the plugs that the fall of pressure between $P$ and $M$ is equal to the fall of pressure between $P$ and $N$, the pressures at the points $M$ and $N$ are equal, and no current will flow through the galvanometer when the key is depressed, and the needle will not be deflected. The bridge is then **Balanced**. In this case

$$E\frac{x}{x+b}=E\frac{r}{r+a}.$$

or, what is the same thing,

$$\frac{x}{b}=\frac{r}{a}.$$

From this proportion we get $x=r\frac{b}{a}$. That is, *the unknown resistance of X is equal to the resistance of R, multiplied by the resistance of B, divided by that of A.* Put in the form of a proportion this may be written

*x is to r as b is to a; or x is to b as r is to a.*

The solution of either of these proportions gives the results presented above. If $a$ and $b$ are equal, and the bridge is balanced, $r$ must be equal to $x$, so that the resistance of the unknown **Branch** or **Arm** of the bridge is given at once by the resistance of the coils in circuit at $R$. The resistance of $A$, in Fig. 90, is ten times as great as that of $B$, and therefore the resistance of $R$ is ten times that of $X$, and $x$ is therefore equal to 1.5 ohms. If the resistance of $B$ had been ten times as great as that of $A$ when the bridge was balanced, $R$ would have been one-tenth as great as $X$ instead of ten times as great. The arms $A$ and $B$ are generally called the **Ratio Arms** of the bridge, and $R$ the rheostat. In measuring a resistance it is well to begin with the ratio arms of equal resistance, changing their ratio to $\frac{1}{10}$, $\frac{1}{100}$, etc., as is shown to be desirable as the balancing proceeds. If it is found that the unknown resistance is of low value, the bridge arms should be of as low resistance as will give the needed ratio, while for high resistance the opposite is true.

## PROBLEMS

*A.* Suppose a resistance is to be measured by a bridge, and after the bridge is balanced the rheostat resistance ($R$) reads 15.6 ohms, when the ratio arms are 100 ($A$) to 10 ($B$), what is the value of the unknown resistance? *Ans.* 1.56 ohms.

*B.* Suppose $R$ reads 2600, and $A$ and $B$ are 10 and 1000 respectively when a balance is obtained, what is $X$? *Ans.* 260,000 ohms.

*C.* If the *R* arm of a bridge contains resistance coils from 1 to 10,000 ohms, what will you make the ratio of the ratio arms in order to measure 1,000,000 ohms, supposing that these arms each contain coils of 1, 10, 100, and 1000 ohms resistance? *Ans.* $A:B::1:1000$.

*D.* If in Example *C* the unknown resistance is .01 ohms, what must be the ratio? *Ans.* $A:B::1000:1$.

*E.* If the *R* arm of a bridge contains resistance coils from 1 to 10,000 ohms, what resistance would you give the three known arms to measure 625,500 ohms? *Ans.* $R = 6255$, $A = 10$, and $B = 1000$.

*F.* If in Example *E* the unknown resistance was .625, what would be the arms? *Ans.* $R = 625$, $A = 1000$, and $B = 1$.

**164. Usual Form of Wheatstone Bridge.** — The Wheatstone bridges that are commonly used are not made up from three separate resistance boxes as indicated in Figure 90. The common forms of Wheatstone bridge contain all the resistance coils in one box, and the coils are connected in such a way that they form a bridge. Binding posts (generally marked *B*, *G*, and *X*, or *R*) are arranged at the proper points for connecting the battery, galvanometer, and unknown resistance which is to be measured to the bridge.

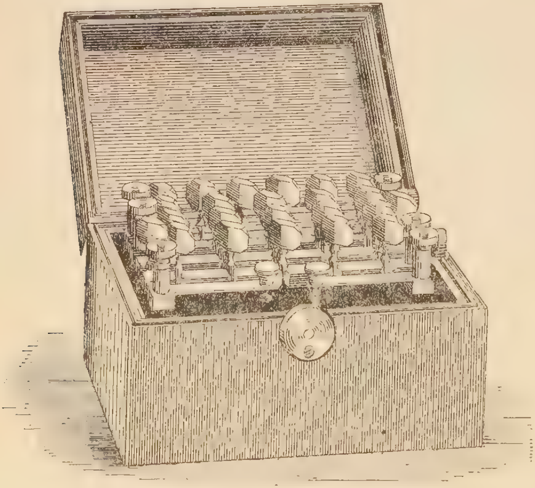

FIG. 91. — Bridge of Post-office Pattern.

Figure 91 shows such a bridge made up in a box so as to be portable. At the front are seen the battery and galvanometer keys. This form of bridge is often called the **Post-office Pattern**, because its arrangement is similar to the bridge used by the British department of postal telegraphs.

Figure 92 shows another way in which the resistance coils are often arranged to make a very accurate and convenient bridge for use in laboratories where it may be permanently fixed.

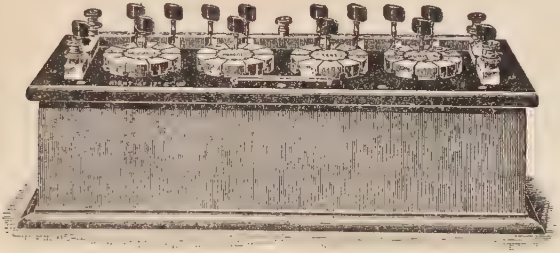

FIG. 92. — Bridge of Dial Pattern.

**165. Accuracy of Bridge.** — Measurements of resistance may be made with a fine bridge to a remarkable degree of accuracy. In fact, the ease and accuracy to be obtained in bridge measurements are only rivalled in weighing with fine balances. It is not unusual to have the resistance coils of a fine bridge adjusted so accurately that the error, when used at some fixed temperature, is less than $\frac{1}{50}$ of one per cent of their desired value which is represented by a standard coil, — that is, their error is less than two parts out of ten thousand when the coils are at the fixed temperature. In adjusting the coils of a resistance box so closely, or in accurately measuring a resistance by a bridge, careful account must be taken of the temperature. Even if the resistance coils of a bridge were exactly correct at one temperature they would not be correct at another; but corrections may be made for the **Temperature Error.**

**166. Testing Sets.** — It is frequently convenient to have a portable bridge which is entirely self-contained — that is, the box of which contains the galvanometer and battery as well as the resistance coils and keys. In this case all that is necessary to make a measurement of resistance is to connect the unknown resistance to the proper binding posts, press the keys, and adjust the plugs till the galvanometer gives no deflection. Such bridges are called **Testing Sets**. One is shown in Figure 93. The resistance coils of testing sets and other less expensive bridges are usually adjusted with such care that their error at ordinary temperatures does not exceed $\frac{1}{5}$ of one per cent.

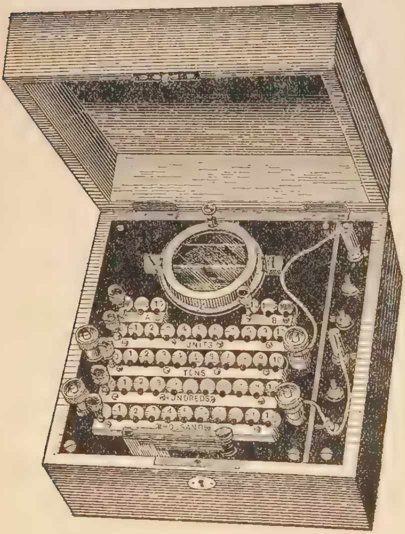

FIG. 93. — Commercial Testing Set.

**167. Manipulation.** — When resistance measurements are being made with a bridge, the battery key should be depressed before the galvanometer key, or irregular and incorrect indications will often be given on account of the self-induction of the unknown resistance. This is particularly true when the unknown resistance consists of the windings of an electromagnet or any of the windings of a dynamo. Great care should always be exercised not to injure the galvanometer or the fine wire coils by passing too great a current through them.

**168. Meter Bridges; Measurement of Low Resistances.** — For very accurate comparisons of two resistances, as when the value of a standard resistance coil is to be determined in terms of a mercury column or of another coil, the Wheatstone bridge is made up in another form (Fig. 94). Here we have two arms of the bridge, $A$ and $B$, made up of a uniform wire of high resistance and small temperature coefficient. The other two arms contain the two coils. The galvanometer terminal corresponding to $M$ (Fig. 90) is made up by means of a binding post, but the terminal corresponding to $N$ is arranged so that contact may be

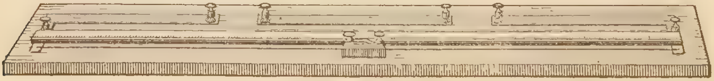

FIG. 94. — Meter or Slide Wire Bridge.

made at any point along the **Bridge Wire.** When the galvanometer contact is placed at the point on the bridge wire which gives a balance, the resistances of the parts of the bridge on each side of the galvanometer contact are in the same ratio as the two resistance coils, according to the bridge formula already developed.

When the bridge wire is calibrated, that is, when the resistance per centimeter of length at every point of the wire is determined, the ratio of the resistance of the two coils is given by the ratio of the resistances of the two parts of the wire. When the bridge wire is very uniform and the measurement is not required to be very exact, the resistances of the two parts of the wire may be taken to be proportional to their lengths. Bridge wires may be made of German silver, but those intended for very accurate measurements are usually made of an alloy containing platinum and silver, or platinum and iridium. Bridges of this form are usually called **Slide Wire, Divided Wire,** or **Meter Bridges.**

### PROBLEMS

*A.* The lengths of the bridge wire on either side of the galvanometer terminal of a slide wire bridge are each 50 cm. If the $R$ arm contains 1.2 ohms when a balance is obtained, what is the unknown resistance? *Ans.* 1.2 ohms.

*B.* Suppose in Example $A$ the length of the wire on the side next the unknown resistance had been only 4 centimeters, what would have been the unknown resistance? *Ans.* .05 ohms.

**169. Measurements of High Resistances.** — Measurements of very great resistances, such as the **Insulation Resistance** of a well-insulated wire between its conductor and the ground, often require a higher power than may be conveniently reached by a bridge. In this case, a fine reflecting galvanometer and a large testing battery are generally used. The **Testing Battery** usually consists of silver chloride cells put up in sets of 50 or 100 cells in a box, so as to be portable. The galvanometer and battery are connected in series with some large known resistance, and the deflection of the galvanometer is read. Then the known resistance is removed from the circuit and that which it is desired to measure is inserted in its place. The deflection of the galvanometer is again read, and the unknown resistance may be calculated from the ratio of the two deflections and the value of the known resistance. This is a modification of the substitution method described at the opening of this chapter. The known or **Standard Resistance** is usually from 25,000 to 1,000,000 ohms in resistance. One million ohms is called a **Megohm**, the prefix "meg" coming from a Greek word meaning great.

**170. Use of Shunt Boxes.** — The insulation resistances of wires and cables that are measured by this process are frequently as great as thousands of megohms, so that it is necessary to use a very fine galvanometer to get readable deflections through them, and the galvanometer must be shunted[1] when a deflection is taken with the standard resistance in circuit. Galvanometers usually have corresponding shunt boxes sold with them which have three coils marked respectively $\frac{1}{9}$, $\frac{1}{99}$, $\frac{1}{999}$. When the shunt box is connected in parallel with the galvanometer, either of these shunts may be placed in the circuit by means of a plug, or the shunt circuit may be broken. When a shunt is plugged into circuit, $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ part of the whole current flows respectively through the galvanometer.

As an example, suppose that it is desired to measure the insulation resistance of an electric light cable one-half mile long; a fine galvanometer, a testing battery of 200 cells, and a standard resistance of one-half a megohm being available. When connected up and shunted by the $\frac{1}{999}$ shunt, the galvanometer gives a deflection of one hundred scale divisions. Then its constant, or the resistance of the circuit in megohms which would be indicated by a deflection of one scale division when the galvanometer is not shunted, is $100 \times 1000 \times \frac{1}{2} = 50{,}000$, since 1000 is the multiplying power of the shunt and $\frac{1}{2}$ the value of the standard resistance in megohms. Now when the standard resistance is removed from the circuit and in its place one end of the circuit wire is attached to the conductor of the cable and the other end to the ground, the reading of the galvanometer without a shunt is, we will say for illustration, 50. The insulation resistance of the cable is $\frac{50000}{50} = 1000$ megohms.

The insulation resistance of a similar cable for a length of one mile is 500 megohms, since the cable which was measured is one-half mile long and the paths for the current to leak out of the two half-miles which constitute one mile are in parallel.

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[1] Article 154.

Other methods of measuring high resistances and special methods of measuring very low resistances are sometimes used, but they need not receive attention here.

## PROBLEMS

*A.* Suppose a galvanometer of negligible resistance without a shunt gives a deflection of 100 when connected in series with a battery and standard resistance of 100,000 ohms. If the deflection becomes 25 when an unknown resistance is substituted, what is the galvanometer constant, and what the unknown resistance? *Ans.* 10 megohms; .4 of a megohm.

*B.* If in place of the standard resistance terminals of Example *A* one end of an insulated telegraph line and a connection to the ground be substituted, and the deflection becomes 50, what is the insulation resistance of the line? *Ans.* 200,000 ohms.

*C.* A galvanometer when used with a certain battery has a constant of 20,000 megohms. If an unknown resistance be placed in circuit and the deflection is 100 when a $\frac{1}{99}$ shunt is used, what is the resistance? *Ans.* 2 megohms.

*D.* Suppose a reflecting galvanometer shunted with the $\frac{1}{999}$ shunt gives a deflection of 80 when using a certain battery, the standard resistance being 5,000 ohms; then suppose the deflection is 120 with the $\frac{1}{9}$ shunt when a certain resistance is substituted for the standard, other things being unchanged, what is the value of the resistance? *Ans.* $\frac{1}{3}$ megohm.

*E.* If the battery and galvanometer of Example *D* be connected to another unknown resistance and the deflection becomes 50 when a $\frac{1}{99}$ shunt is used, what is the resistance? *Ans.* 80,000 ohms.

*F.* A galvanometer of 1000 ohms resistance deflects one division when .000001 of an ampere passes through it; what is the resistance of a coil which is placed in series with it and a battery of 2 volts pressure, if the deflection then is 50 scale divisions? *Ans.* 39,000 ohms.

**171. Volt and Current Method of measuring Resistance.** — The statements of Article 92 make it clear that the resistance of a wire may be calculated from Ohm's Law, provided that we know the pressure across the terminals of the resistance to be measured and the current passing through it. The formula is

$$R = \frac{E}{C}.$$

This is a very satisfactory and common method. A voltmeter is used for measuring the pressure, and an amperemeter for measuring the current. The connections are as shown in Figure 95. The method and the instruments will be explained in a later chapter.

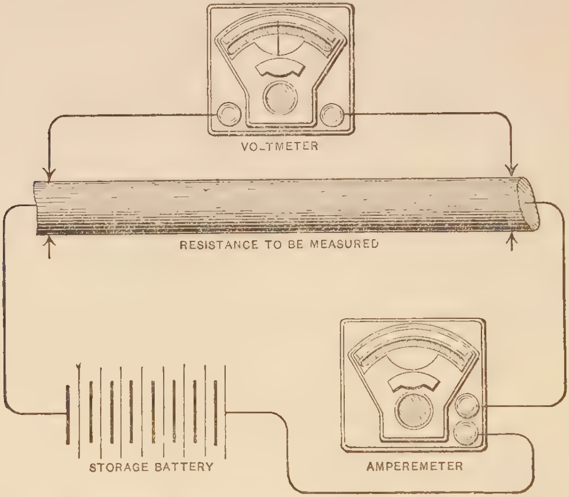

FIG. 95. — Arrangements for measuring Resistance by Amperemeter and Voltmeter.

## QUESTIONS

1. Explain how to measure resistance by substitution.

2. Why does the galvanometer constant not need to be known in measuring resistance by substitution?

3. What precaution must be observed with reference to connecting wires in measuring resistance by substitution?

4. What is a rheostat?

5. Describe the construction of a resistance box.

6. Why is German silver wire used in resistance boxes?

7. Why is the wire of resistance boxes wound double?

8. If a plug is inserted into one of the holes of a resistance box, is resistance inserted in or removed from the circuit?

9. How is the resistance of a resistance coil adjusted? How is the wire insulated?

10. What is a Wheatstone bridge?

11. How is a Wheatstone bridge made?

12. When is a bridge said to be balanced?

13. What proportion must the resistances of the bridge arms have in order that the bridge shall be balanced?

14. If the galvanometer needle deflects to the right when the fall of pressure is greater in $R$ than in $X$, what will happen if the fall of pressure in $X$ becomes the greater?

15. When a bridge is balanced, what is the unknown resistance $x$ equal to in terms of the resistances of the other arms?

16. What are the "ratio arms" of a bridge?

17. When the ratio arms $A$ and $B$ are equal in a bridge, why must $R$ and $X$ be equal when the bridge is balanced?

18. If ratio arm $A$ (Fig. 90) is ten times larger than $B$, what will be the relative sizes of $R$ and $X$ when the bridge is balanced? What if $B$ is larger than $A$?

19. Describe the post-office pattern bridge.

20. What is the temperature error in a bridge?

21. How accurate can bridges be made?

22. Describe a testing set.

23. Why should the battery key of a bridge be depressed before the galvanometer key?

24. What is a meter bridge?

25. How is a meter bridge used?

26. What is the slide wire in a meter bridge made of?

27. Why is a meter bridge especially desirable for measuring low resistances?

28. How may insulation resistances be measured?

29. What is the use of a shunt in measuring very high resistances by means of a galvanometer?

30. How can a high resistance be measured by using a galvanometer, when its constant, as explained in Article 153, is known?

31. Should a galvanometer have a great or a small number of turns for measuring high resistances? For measuring low resistances? Why?

32. How can the resistance of a circuit be determined by measurements of current and pressure?

33. When is a coil or circuit "short-circuited"?

# CHAPTER XIII

## MEASUREMENT OF ELECTRIC CURRENTS AND PRESSURES

**172. Principles of Instruments for Current Measurement.** — We have already seen that electric currents may be measured by taking advantage of three different and independent effects of the current. These are: —

1. *The electrochemical effect.*
2. *The magnetic effect.*
3. *The heating effect.*

By taking advantage of the first effect we may measure currents by the use of voltameters;[1] as a result of the second effect we measure currents by means of galvanometers;[2] from the third effect we may measure currents by means of the expansion of a wire which is heated by the passage of the current through it.[3]

Voltameters, as said in Chapter XI, are principally used for calibrating galvanometers or for similar purposes, as they are not sufficiently convenient for general use. The liquid must be kept fairly pure and of the proper density. Conveniences must be available for cleaning, drying, and accurately weighing the cathodes. In order that a satisfactory measurement of the current may be made, the period during which it flows through a voltameter must be considerable. They have been found particularly useful for only one purpose in everyday measurements; that is, as a meter such as was formerly used by many of the Edison Illuminating Companies.[4] Voltameters were used for this purpose in the early days of electric lighting with incandescent lamps, and have continued in use until lately; but even for this purpose they have been displaced by the excellent mechanical meters that are now to be had.

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[1] Articles 155 to 159.

[2] Articles 144 to 154.

[3] Article 112.

[4] Article 159.

**173. Amperemeters and their Uses.** — Nearly all our common instruments for measuring currents depend upon the magnetic effect of the current for their indications, and are really modified galvanometers with pointers to show the deflections.

Galvanometers or other instruments intended especially for convenient use in everyday measurements of currents are generally called **Amperemeters** or **Ammeters**, because they measure amperes. Amperemeters are made in various forms, all more or less portable. Almost every manufacturer of dynamos or other electrical machinery manufactures amperemeters which may be used in service with his machines. Amperemeters are universally used where electricity is used, and they are made to measure currents consisting of only a few thousandths of an ampere, or **Milliamperes** (*milli* comes from a Latin word meaning thousand), up to the enormous currents generated by some of the larger electric lighting plants, reaching to thousands of amperes. In large electric lighting plants or works, many amperemeters may be seen mounted on the wall or on a board among switches for controlling the current. These are used to show the dynamo attendants how much current is being generated by the plant at any moment, and what proportion is furnished by each dynamo.

Amperemeters are used in laboratories to determine the current used in experiments, and to determine the amount of current used in the operation of electric lamps, electric motors, or other electric devices. Physicians use amperemeters to measure the currents used in the electrical treatment of their patients. For the latter purpose the currents are usually measured in milliamperes. The currents used in telegraphy are also usually measured in milliamperes, and the currents used in operating telephones are usually measured in **Microamperes**, or millionths of amperes (*micro* comes from a Greek word meaning small). Amperemeters that are specially made to measure thousandths of amperes, or milliamperes, are called **Milliamperemeters**. Externally, milliamperemeters look like ordinary amperemeters, to which they bear the same relation that a very sensitive galvanometer bears to a similar but less sensitive instrument. Amperemeters measure the current flowing through a circuit, and they are therefore *connected in series in the circuit.*

**174. Mechanism of Magnetic Amperemeters.** — The mechanical details entering into the construction of magnetic amperemeters differ very widely. They may be roughly divided into three classes: —

1. Those having soft iron parts which are moved by the magnetic attraction set up by the current in the coils of the instrument.

2. Those having permanently magnetized parts which are acted upon by the magnetic force set up by a current in the coils of the instrument, either the coil or the magnet moving.

3. Those having no iron in their construction, but having two coils, one of which is moved by magnetic forces exerted between them when a current flows in both.

The moving parts of amperemeters are usually mounted on pivots which are carefully wrought to reduce the friction to a small value.

If the magnetic force caused by a current in the coils of an amperemeter had nothing except the friction to overcome, every current would pull the pointer entirely across the scale to the stop. It is desirable to construct the instrument so that the movement of the pointer is proportional to the current in the windings, and a proper force must therefore be arranged to hold the pointer back. This may be done by properly **Counter-weighting** the moving parts, so that the magnetic force must raise them against the force of gravity, or by arranging a proper spring to oppose the magnetic force. Figure 96 shows an instrument in which a curved core *G* of soft iron wire is drawn into a solenoid of wires when the current flows through the winding. The weight of the moving parts of the instrument serves to keep the pointer at zero when no current flows. When a current flows, it exerts an attraction on the iron wire core, which overcomes the effect of the weight of the moving parts, the iron core is attracted into the coil a certain

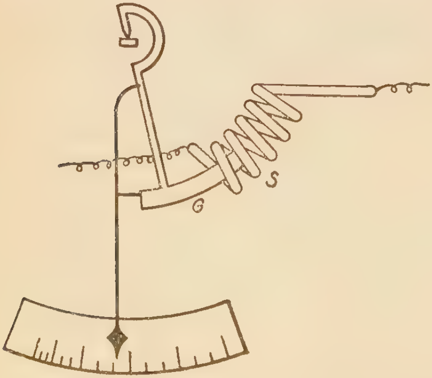

FIG. 96. — Simple Form of Amperemeter.

distance, as illustrated in the Figure, and the pointer moves proportionally. This instrument evidently belongs to the first class.

Instruments of the first class may be cheaply constructed, and formerly were commonly made by dynamo builders for use in electric light plants.

**175. Amperemeters using Permanent Magnets.** — Instruments having soft iron in their moving parts cannot readily be made extremely accurate because the iron does not always respond equally to the same magnetic changes on account of its coercive force ;[1] consequently instruments of the first class can only be used, as a rule, where great accuracy is not essential. It is sufficient for the amperemeters used in many electric plants to be correct within five per cent, and instruments of the first class serve very well. For testing which requires greater accuracy, instruments which belong to the second and third classes must be used.

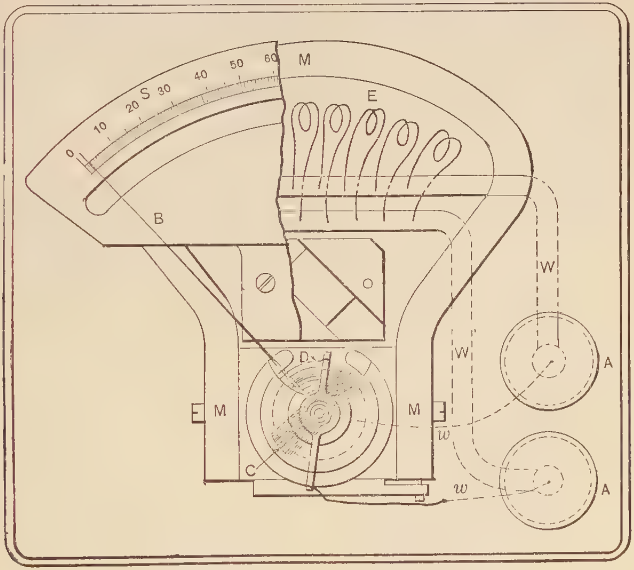

FIG. 97. — Plan of Weston Amperemeter.

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[1] Article 127.

These can be made so that their readings do not vary more than one-half of one per cent from true values when they are used with proper care.

Figure 97 shows a Weston amperemeter, which is practically a D'Arsonval galvanometer with the moving coil mounted on pivots and arranged with a pointer to play over a scale; and the whole is arranged in a very convenient, portable form in a self-contained case which is not shown in the figure. This instrument is a representative of the second class. *AA*, in the figure, are the **Binding Posts** of the instrument by means of which wires may be connected to the instrument. Large wires *WW* run from these to the shunt *E*, and small wires *ww* to the armature coil *C*. This coil is mounted on pivots so that it may move between the pole pieces of the permanent magnet *MMM*. When a current flows through the coil it tends to turn so that its magnetism may be parallel to the lines of force of the permanent magnet. The motion is opposed by the springs *DD*, so that it is proportional to the current. The pointer *B* is attached to the coil and moves over the scale *S*, so as to indicate the amount of current flowing through the instrument. The object of the shunt *E* is explained in Article 181. Figure 98 shows an end view of one of these instruments with a portion of the construction cut away so as to show the works. The movable coil and permanent magnet are clearly visible in both of the illustrations. Similar letters in Figures 97 and 98 refer to the same parts. The soft iron cylinder, which is so plainly shown in Figure 98, is used to improve the magnetic circuit of the magnet. It is stationary, and the conductors of the coil move between it and the pole pieces of the magnet. A cyclindrical soft iron core of the same character is shown in the D'Arsonval galvanometer of Figure 83.

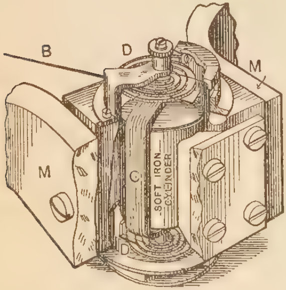

FIG. 98. — Sectional End View of Weston Amperemeter.

Weston or similar amperemeters are used a great deal where accurate portable current measuring instruments are required, because they are accurate, convenient, and well made. During the past few years the best generating stations have discarded the inaccurate forms of amperemeters previously described, and have adopted superior instruments belonging to this class.

**176. Electrodynamometers.** — Magnetic instruments belonging to the third class are really not galvanometers, but are called **Electrodynamometers**, because their indications are caused by the magnetic pull of the fixed and movable coils upon each other which is caused by the current flowing in them. Figure 99 shows the ordinary form of the electrodynamometer when arranged for use as an amperemeter. This is often called the **Siemens Electrodynamometer.** One coil *F* in this instrument is fastened to the frame of the instrument, and the other coil *M*, which stands at right angles to the first, is suspended by a heavy silk fibre so that it is free to move. The end of the wire composing the movable coil dips into little cups *CC*, containing mercury, which are connected with a circuit so that the current can enter and leave the coil. The movable coil is attached to a spring *G*, the other end of which is connected to a thumbscrew *T*, called a **Torsion Head**, by means of which this spring may be twisted. When a current flows in the coils, the magnetic force tends to turn the movable coil around so as to place it parallel with the fixed coil.[1] This force is balanced by twisting the spring by means of the thumbscrew. The amount of twist as shown by a pointer *B*, attached to the screw, is proportional to the force exerted by the coils on each other; and this force is proportional to the square

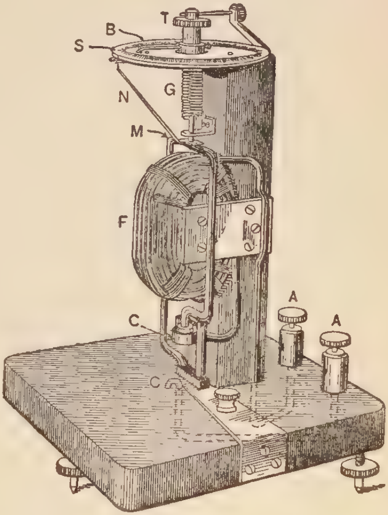

FIG. 99. — Siemens Electrodynamometer.

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[1] Article 143.

of the current flowing in the coils, since the magnetism set up by each coil is proportional to the current, and they act on each other mutually. The pointer *N* indicates whether the movable coil is at its zero position. The "binding posts" for connecting the instrument into the circuit are shown at *AA*.

**177. The Kelvin Balance.** — Very accurate and permanent standard instruments for measuring currents by their direct magnetic action have been designed, but they have not been made sufficiently portable to bring them into much use. The most important of these are the current balances of Lord Kelvin, formerly Sir William Thomson, one of which is illustrated in Figure 100. The fixed and movable coils in these instruments are parallel to each other and horizontal. The force with which the coils tend to move toward each other when a current flows in them is directly balanced and weighed by means of a slider moving on a scale beam. In order to avoid any effect from the earth's magnetism, coils are placed at both ends of the balance arm and are electrically connected so that the magnetic force of the two sets of coils tends to tip the beam in the same direction, but the effect of the earth's magnetism on the two swinging coils is balanced.

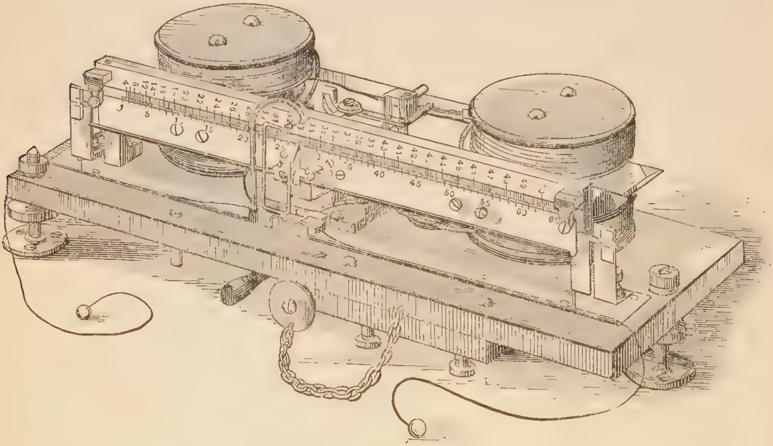

FIG. 100. — Kelvin Balance.

**178. Hot Wire Amperemeters.** — Instruments utilizing the heating effect of the current are usually called **Hot Wire Instruments.** If the heated wire is carefully enclosed so that its temperature is not affected by air currents, it will rise to a definite number of degrees in temperature for every current that is passed through it, and the rise is proportional to the square of the current. The length of the wire increases practically in direct proportion to its rise in temperature when it is heated, and the length again decreases when the wire is cooled. Consequently, when currents of different strengths flow through a wire it will take up a corresponding length with each current, and measuring its length therefore measures the square of the current. A simple form of amperemeter depending on this action is shown in Figure 101. A long, thin wire is clasped at one end in a stationary binding post, and the other end is wrapped around and fastened to a small wheel of metal. This wheel is supported on steel pivots, one of which is connected to another binding post. The wire is kept under a constant strain by means of a spring, which is also fastened to the periphery of the wheel. When the wire is heated and lengthens, the wheel is turned by the contraction of the spring, and when the wire is again cooled and contracts it pulls the wheel back to its old position. The wheel carries a pointer, which moves over a graduated scale, so that the position of the wheel may be quickly seen when any current flows in the wire.

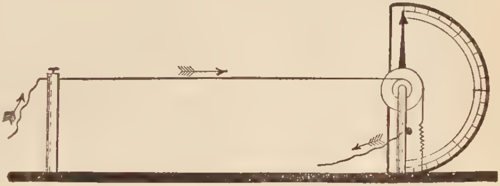

FIG. 101. — Simple Hot Wire Amperemeter.

**179. Amperemeter Scales.** — Many amperemeters have scales that are uniformly graduated, and the readings can only be converted into amperes by consulting a calibration curve[1] or a table giving the values of different readings in amperes. Other instruments are constructed so that the readings may be multiplied by a fixed constant which has been experimentally determined, for the purpose of converting them into amperes. In still other instruments, which are said to be **Direct Read-**

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[1] Article 153.

ing, the scales are so divided and marked that the divisions read directly in amperes. It is needless to say that direct reading instruments are the best and most convenient for use.

**180. Alternating Current Amperemeters.** — Currents which rapidly alternate in direction, as do the currents of many electric light plants, cannot be measured by magnetic instruments having permanent magnets, since the tendency of such currents is to first deflect the moving parts in one direction and then in the other and the pointer stands still or nearly so. Such currents can be measured by magnetic instruments of the first class because *the soft iron core is always attracted by a coil in which a current flows* without regard to the direction of the current. The iron cores in instruments designed to measure these **Alternating Currents** must be built up from thin strips or fine iron wires, so that currents shall not be set up in them by the reversals of the magnetism.[1] An instrument in which a thin strip or disk of iron is used is commonly called a "Magnetic Vane" instrument. One of this type is illustrated,

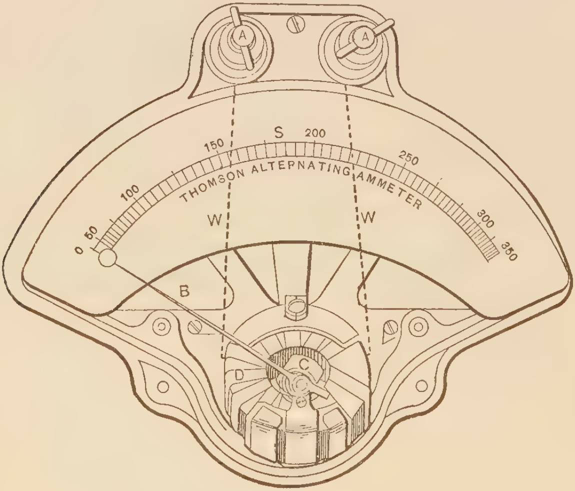

FIG. 102. — Plan of Thomson Alternating Current Amperemeter.

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[1] Article 139.

with its cover taken off so as to expose the working parts, in Figure 102. The parts of this instrument are indicated by the letters, where *D* is the current coil, *C* the thin movable iron vane, *B* the needle, *S* the scale, and *AA* the binding posts which are connected to the coil *D* by the wires *WW*.

Electrodynamometers and other instruments which depend for their indications upon the mutual attractions of two coils may be used to measure alternating currents, because the current reverses in the two coils at the same instant, and the magnetic attraction between the coils is, therefore, always in the same direction. The heating effect of currents is independent of their direction, so that hot wire instruments may also be used to measure alternating currents.

**181. Shunted Amperemeters.** — When very large currents are to be measured, it is often inconvenient and expensive to build an amperemeter of sufficient capacity for the purpose. In this case an amperemeter of small capacity may be shunted by a copper or German silver wire or rod, and the shunted instrument may then be calibrated and used to measure the large current. This arrangement has become quite universal in the large electric light works where very great currents are to be measured, and it is not uncommon in ordinary portable instruments. For instance, nearly all Weston amperemeters consist of a milliamperemeter arranged with a proper shunt inside the case, as illustrated in Figure 97, so that the desired range is obtained.

**182. Voltmeters.** — The commonest method of measuring an electric pressure is to measure the current which it causes to pass through a known high resistance. This resistance may be connected permanently in the circuit of a sensitive amperemeter, such as a milliamperemeter, and the instrument may be calibrated so that its indications may be readily converted into volts.

Instruments that are used for everyday measurements of electric pressures are called **Voltmeters**, because they measure volts. By properly dividing the scale upon which the indications are made, voltmeters may be made direct reading. Figure 103 shows a Weston direct reading voltmeter, in which the working parts are similar to those of the amperemeter shown in Figure 97, but in the voltmeter a high resistance spool of fine wire is placed in series with the D'Arsonval galvanometer coil, instead of a low resistance shunt being placed in parallel with it, as is done with the amperemeter.

The voltmeter that is shown in the figure has three binding posts. The instrument is connected to a circuit by binding posts *AA'* for ordinary use. Then, when the key *K* is closed, current flows through the high resistance coil *E* and the movable coil *C*, and the pointer is deflected a distance proportional to the electrical pressure of the circuit. When the instrument is connected to the circuit by means of the binding posts *Aa*, and the key is closed, the current flows through the coil *e* and thence through the movable coil *C*. The coil *e* is adjusted so that the resistance between binding posts *Aa* is just one-twentieth of the resistance between binding posts *AA'*, and the instrument is therefore twenty times more sensitive when the binding posts *Aa* are used. If two volts cause a movement of the pointer a certain distance across the scale in one case, it requires forty volts to cause an equal movement in the other case. Many voltmeters are made with only one resistance coil and only

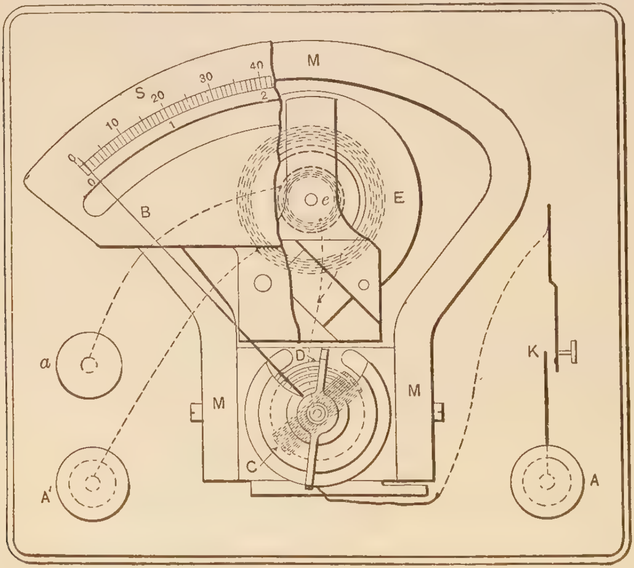

FIG. 103.—Plan of Weston Voltmeter.

one scale. The letters in this figure refer to the same parts as similar letters in Figures 97 and 98.

Voltmeters are also made upon the same principle as the amperemeter shown in Figure 96, but the coil is wound with many turns of fine wire, making a high resistance, instead of being made with a few turns of coarse wire. This form of voltmeter has the same fault as the amperemeter of the same class — that of being inaccurate; and it, therefore, is not as satisfactory for use in many places as more accurate instruments made with very little or no iron in their working parts.

In electric light plants where current is produced for use in incandescent lamps, it is very important that the pressure be kept as closely as possible to the exact pressure with which the lamps were designed to be used. Consequently, in such places the most accurate and reliable voltmeters or **Pressure Indicators**, as they are sometimes called, are needed.

Voltmeters of the type just described are usually made with a very high resistance, so that only a small current flows through them, and they therefore may be used without causing an appreciable change of the current in a circuit.

Figure 104 shows a hot wire voltmeter, which is called after its inventor, Cardew. This was largely used at one time to measure alternating electric pressures, and it is still used to a considerable extent in England for that purpose. The indications of this instrument are dependent upon the expansion of a very fine platinum-silver wire ($\frac{25}{10000}$ inch in diameter), through which the current passes. This wire is from 8 to 12 feet long, and of such high resistance per foot that its resistance alone is sufficient for use up to a pressure of 120 volts, but another resistance coil is put in series with the instrument when it is used to measure high pressures.

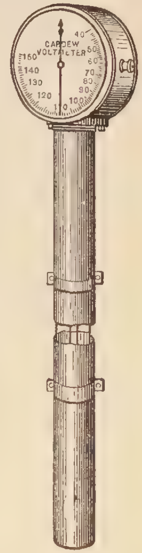

FIG. 104. — Cardew Voltmeter.

Voltmeters are used for measuring pressures, and therefore are not intended to be connected in series in a circuit. They are designed to be connected between the points whose difference of pressure it is desired to measure.

**183. Electrostatic Voltmeters.** — Another entirely distinct method of measuring electric pressures is by means of electrometers. In Article 13 it is explained that electrometers are instruments for determining the quantity of electricity on a charged body, by measuring its attraction for another charged body. It is also explained in Article 17 that electricity at rest at a high pressure constitutes a positive charge, and electricity at rest at a low pressure constitutes a negative charge. It is a fact that the terms positive and negative charge must be taken as relative terms, exactly as are the terms high and low pressure. An electrometer is an instrument by means of which the attraction between two charges may be measured.

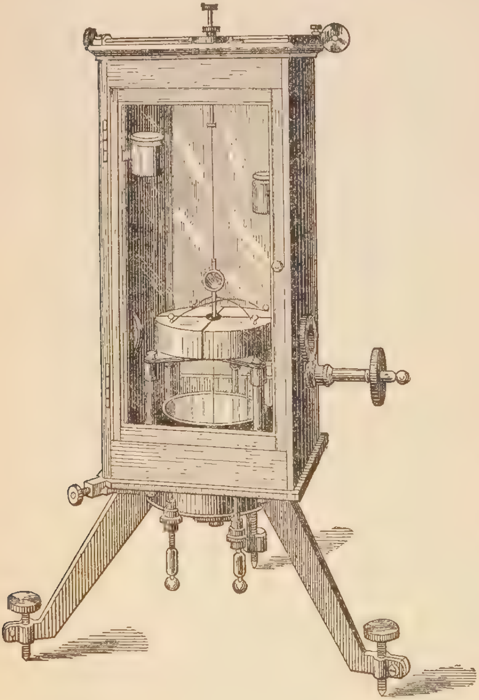

FIG. 105. — Quadrant Electrometer.

One form of electrometer is shown in Figure 105. In this electrometer there is a needle, made of aluminum, and a sort of metal pill box, cut into quadrants (*quarters*). If the opposite quarters are connected together, as shown in the figure, and one pair of quarters are connected to the needle, the needle tends to be deflected by the attraction and repulsion of the charges, when a charge of one sign is communicated to the needle and its connected pair of quadrants, and a charge of the opposite sign to the other pair of quadrants. The force with which the needle tends to turn may be measured by a torsion head, as in an electrodynamometer, or by suspending the needle so that a certain portion of its weight must be lifted as it turns.

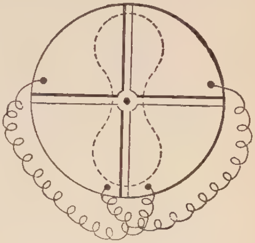

FIG. 105*a*. — Plan of Quadrants and Needle for a Quadrant Electrometer.

If the two poles of a battery are connected to the two terminals of the electrometer, one terminal of the instrument is brought to a high pressure and the other to a low pressure, on account of the action of the battery, and they, therefore, hold corresponding positive and negative charges. The deflection of the needle indicates the pressure developed by the battery. This pressure may be directly read off in volts, if the instrument has been properly calibrated. In the same way, if the two ends of a resistance through which a current is flowing, such as an electric lamp, are connected to the electrometer, one terminal of the instrument is brought to a high and the other to a low pressure, and the deflection of the needle shows the difference of pressure between the ends of the resistance.

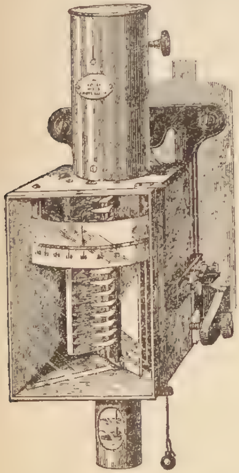

FIG. 106. — Electrostatic Voltmeter.

Electrometers made for use in everyday measurements of electric pressure are usually called **Electrostatic Voltmeters.** They are particularly useful for measuring alternating electric pressures, since the polarity of the two pairs of quadrants and of the needle change at the same instant, and consequently the needle is deflected continuously in the same direction. Figure 106 shows such a voltmeter, arranged for use in light and power stations. It is seen from the figure that there are a large number of sets of quadrants and needles, one above the other. This is to make the tendency to deflect stronger. Figure 107 shows an electrostatic voltmeter made for measuring pressures of several thousand volts.

**184. Measuring Pressures by Comparison with Standard.** — Still another method of measuring an electric pressure is to compare it with a standard pressure. If a known large resistance is connected between the points whose difference of pressure it is desired to measure, a small current will flow through the resistance, and the pressure will fall along the path of the current in proportion to the resistance passed over. Now suppose the terminals of a battery cell *S* (Fig. 108) are connected in series with a galvanometer *G* to certain points on the resistance, in such a way that the pressure of the cell is in opposition to the difference of pressure between the points. If the latter pressure is greater than that of the cell, a current will flow through the cell and galvanometer, and the galvanometer needle will be deflected. The same thing will occur if the pressure of the cell is the greater, but the current and the galvanometer deflection which it produces will be reversed.

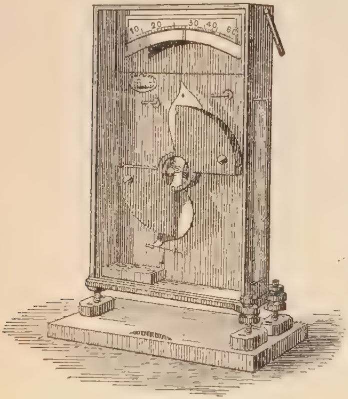

FIG. 107. — Electrostatic Voltmeter for indicating High Pressures.

Finally, if the portion of the resistance which is between the terminal connections of the cell is so adjusted that no current flows through the galvanometer, the fall of pressure through that part of the resistance exactly equals the pressure produced by the cell. The total pressure to be measured is then equal to the pressure developed by the cell, multiplied by the ratio of the total resistance to the balancing resistance. In the figure, the pressure of the cell is marked 1.2 volts, the total resistance is 10,000 ohms, and the

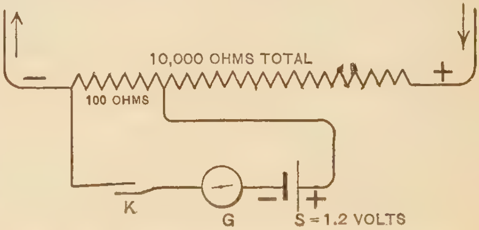

FIG. 108. — Measuring Pressure by Comparison.

balancing resistance is 100 ohms. Assuming a balance, the total pressure must be $1.2 \times 10{,}000 \div 100 = 120$ volts.

**185. Potentiometers.** — A special arrangement for measuring pressures by comparison is often called a **Potentiometer,** and the cells used for the comparison are called **Standard Cells.** It is evident that standard cells must develop a very uniform pressure under all conditions of their use. The best standard cell is that called **Clark's Cell,** after its inventor. This was recommended by the Chicago Electrical Congress to be used as a comparative standard of pressures, and its pressure was given in accordance with experimental tests to be 1.434 volts at 15° centigrade, when set up according to fixed instructions. Professor Carhart and others have endeavored to make a standard cell with exactly one volt pressure.

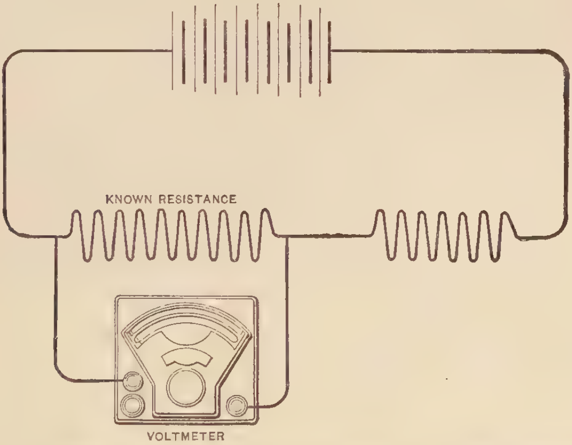

FIG. 109. — Measurement of Current by Voltmeter and Known Resistance.

Portable voltmeters have been made upon the principle of a potentiometer, but without much success.

**186. Indirect Measurement of Current.** — Electric currents may be indirectly measured by means of a known resistance, placed in the circuit through which the current flows, and a voltmeter connected across its terminals. In this case, the voltmeter is used to measure the difference of pressure between the ends of the resistance (Fig. 109), and the current may be at once calculated from Ohm's Law. This process, however, simply amounts to an indirect application of the principle of a shunted amperemeter. It must be remembered that an electromagnetic voltmeter is no more than a milliamperemeter which is graduated to read in volts.

## QUESTIONS

1. What three effects of electricity can be made use of in measuring electric currents?

2. Of what service have voltameters proved in ordinary current measurements?

3. What is an amperemeter?

4. What is an amperemeter used for?

5. What is a microampere?

6. Into what three general classes may amperemeters be divided?

7. Compare the second class of amperemeters with D'Arsonval and ordinary reflecting galvanometers.

8. Why must an opposing spring, or some other arrangement of that kind, be used against the force of the current tending to cause movement in the amperemeter?

9. Describe a Weston amperemeter.

10. What is an electrodynamometer?

11. Describe a Siemens electrodynamometer.

12. Why is the force acting in an electrodynamometer proportional to the square of the current?

13. Describe a Kelvin balance.

14. How is the effect of the earth's magnetism overcome in a Kelvin balance?

15. What is the principle of hot wire instruments?

16. Why do the needles of hot wire amperemeters move in proportion to the squares of the currents?

17. Describe a hot wire instrument.

18. What is a direct reading amperemeter?

19. Why cannot instruments containing permanent magnets be used to measure alternating current?

20. Why can instruments with finely divided soft iron cores be used in measuring alternating currents?

21. Why can electrodynamometers and hot wire instruments be used in measuring alternating currents?

22. What are shunted amperemeters?

23. If an amperemeter of 100 milliamperes range of scale is to be used with a

shunt to measure 100 amperes, what must be the relative resistance of amperemeter and shunt?

24. What is a voltmeter?

25. What is the principle of a voltmeter?

26. What is the difference between a voltmeter and an amperemeter?

27. How can a milliamperemeter, with a large resistance coil in series with it, be calibrated so that it will be a direct reading voltmeter?

28. Are all voltmeters, depending upon magnetic attraction, really amperemeters calibrated to read volts?

29. How is a hot wire amperemeter modified so that it may be used as a voltmeter?

30. What is an electrometer?

31. What is an electrostatic voltmeter?

32. Why does the needle of an electrostatic voltmeter tend to move?

33. What is a potentiometer?

34. What battery cell did the Chicago Electrical Congress adopt as a standard of pressure?

35. Why will the galvanometer needle of a potentiometer show no deflection when the fall of pressure in the resistance, across which the standard cell is connected, is equal to the pressure of the cell?

36. If the resistance included between the terminals of the standard cell of a potentiometer is one-tenth of the total resistance, how much greater is the pressure to be measured than that of the cell?

37. What would happen if an amperemeter were connected in parallel across a circuit instead of in series with the circuit?

38. What would happen if a voltmeter were connected in series with a circuit, as an amperemeter should be, instead of between the terminals of the circuit?

39. If a 100 ampere amperemeter, with a resistance of one-thousandth of an ohm, should be connected between two points in a circuit having a difference of pressure of 100 volts, how much current would instantly pass through the amperemeter? What would be the result?

# CHAPTER XIV

## MEASUREMENT OF ELECTRICAL POWER. CONDENSERS, AND MEASUREMENT OF CAPACITY

**187. Measurement of Electric Power; Wattmeter.** — The electric power which is used in any part of a continuous current circuit may be determined by measuring the current flowing by an amperemeter, and the pressure, or **Voltage** as it is often called, at the terminals of the portion of the circuit, by a voltmeter. The values of these being multiplied together give the power in watts.[1] Instruments are made in which the double measurement and multiplication are all made together, so that their indications are directly proportional to power. Such instruments are called **Wattmeters**, because they measure watts.

The simplest wattmeter is a form of electrodynamometer, in which one coil is wound with many turns of fine wire exactly as though it were to be used as a voltmeter coil, and the other coil is wound with a few turns of coarse wire as though it were to be used in an amperemeter. For convenience we will call the two coils respectively the pressure coil and the current coil. The action of such a wattmeter is best explained by an illustration. Suppose it is desired to measure the power used by an electric motor, then the current coil of the wattmeter is connected in series with the motor, and the pressure coil is connected across the terminals of the motor. The magnetic effect of the current coil is then proportional to the current which flows through the motor, and the magnetic effect of the pressure coil is proportional to the pressure at which the current is supplied to the motor. The indications of an electrodynamometer are proportional to the product of the magnetic effects of the two coils.[2] Consequently, in this case the indications are proportional to current times pressure, or watts, instead of current times current as in the Siemens electrodynamometer. Figure 109*a* shows a portable form of wattmeter with its cover removed so as to show the working parts, which are indicated by letters. *MM* and *OO* are binding posts, the first of which are terminals for the "pressure coil," and the second are terminals for the "series coil" (one of the latter is at the far corner of the instrument and is hidden); *A* is the stationary or fixed coil; *BB* is the movable coil; *P* is the pointer or "needle"; *H* is the scale; *K* is an extra resistance which is placed in series with the pressure coil; *D* is a torsion head by means of which the spring *C* may be turned so as to bring the movable coil, which is attached to it, into the zero position. This position is indicated by the pointer *P′*. When

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[1] Article 110.

[2] Article 176.

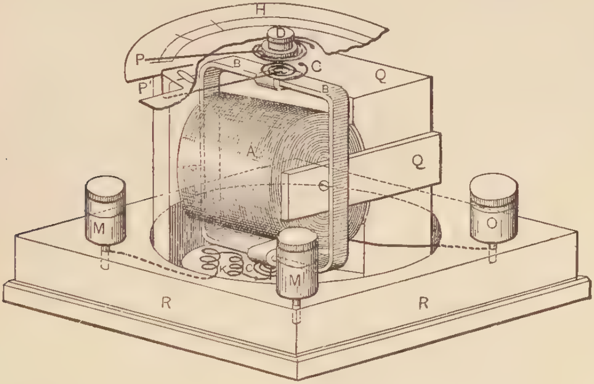

FIG. 109*a*. — Partial Perspective View of Hoyt Wattmeter.

the pointer *P′* points to zero, the pointer *P* which is attached to the torsion head points to the reading of the instrument. *R* and *Q* are the wooden base and supports of the instrument.

Wattmeters are often made so that the needle *P* is directly attached to the movable coil and one end of the spring is attached to the frame of the instrument (instead of to a torsion head), while the other end is attached to the coil. Then the reading of the instrument depends on the amount of motion of the coil, just as was explained in Article 175 with respect to the Weston amperemeter.

Wattmeters may be calibrated by comparing their readings, when connected to a continuous current circuit, with the indications of standard voltmeters and amperemeters. By proper construction and adjustment of their scales they may be made direct reading. Figure 109*b* shows the way in which a wattmeter is connected to a circuit.

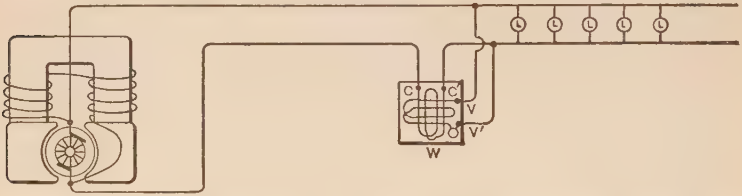

FIG. 109*b*. — Diagrammatic Illustration of Wattmeter, *W*, connected to a Circuit for the Purpose of measuring the Power delivered to Incandescent Lamps or Other Apparatus. *CC′*, *VV′* are the binding posts and *LLL* are the lamps.

It is also possible to make electrostatic wattmeters, and wattmeters based upon other principles.

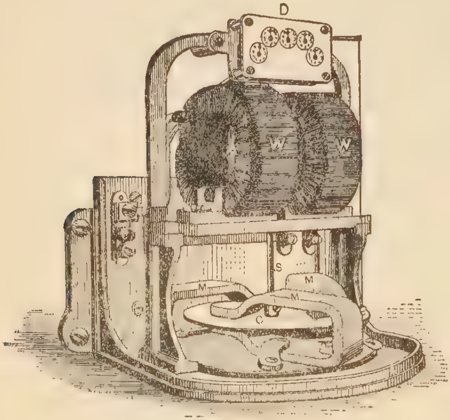

FIG. 110. — Interior of Thomson Recording Wattmeter.

**188. Recording Wattmeters.** — Recording wattmeters may be used to show the amount of power used each month by the customers of electric plants. One of the commonest forms of wattmeters used for this purpose is that shown in Figure 110, known as the Thomson recording wattmeter, after its inventor. This is built like a little electric motor without any iron in its working parts. It is arranged with its revolving part or **Armature** *A* as a pressure coil, and its magnetizing windings *WW* as a current coil. The magnetic pull which tends to make the armature rotate is proportional to the product of the two magnetizing effects, and this is proportional to the watts in the circuit, exactly as in an electrodynamometer.

If the speed of such an armature is made to be proportional to the magnetic pull, it is easily seen that every revolution of the armature means a certain number of watts used for a fixed length of time. Such instruments usually have attached to the spindle of the armature a set of dials *D* like those of a gas meter, which record the revolutions and are so marked that the consumption of electric energy may be recorded in **Watt Hours.** *Watt hours are the product of the number of watts by the number of hours during which the power is used.* Since the dials record a total number of watt hours which are added together, or "integrated," by a meter during the period that it operates, these meters are properly called **Integrating Wattmeters.**

If no external retarding force were applied to the armature of such an instrument, it would run away as soon as placed in service, and in order that its speed may be proportional to the watts the retarding force must be in proportion to the speed. This is very ingeniously arranged in the Thomson recording wattmeter by placing at the bottom of the spindle *S* a flat disk of copper *C*, on either side of which are placed the poles of permanent magnets *M*. The rotation of the disk between the magnet poles generates electric currents in it which are attracted by the magnets and retard the motion of the disk.

Some other meters for use in determining the amount of power consumed by customers, which are externally similar to the Thomson, read **Ampere Hours,** instead of watt hours. An ampere hour is equal to 3600 **Ampere Seconds,** but one ampere second (that is, one ampere flowing for one second) means the transfer of one coulomb of electricity through the circuit. Consequently, the readings of meters which record in ampere hours are directly comparable with the indications of the Edison electrolytic meter which has been mentioned before.[1] Meters which read in ampere hours are sometimes called **Coulomb Meters.**

The reading of ampere hours has no relation to the power consumed in a circuit unless the pressure in the circuit is known, but in the cases where such meters are used the pressure is intended to be kept at a constant known value, so that the watt hours used by each customer may be easily determined. This is done by multiplying the ampere hours reading of his meter by the constant pressure in the circuit.

The wattmeters which have been described here are also satisfactory for use in alternating current circuits, though the relations in such circuits which exist between current, pressure, and power are not so simple as in direct current circuits. The important and interesting features of alternating current circuits are treated in succeeding chapters.

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[1] Articles 159 and 172.

**189. Measurement of the Pressure of a Static Charge.** — The electrical pressure of a conductor carrying a charge of electricity is ordinarily reckoned as the difference between its potential and the average electrical pressure of the earth's surface, which is called zero. This is similar to the reference of levels or heights to the sea level as a zero point from which to start.[1] The electrical pressure of a charged conductor cannot be measured by an ordinary voltmeter, since the charge would be at once dissipated by the current which would flow through the voltmeter when connected between the conductor and the earth. The same is true of condensers in all of their forms. The pressure may, however, be measured by a sufficiently sensitive electrometer or electrostatic voltmeter. For instance, in the case of a quadrant electrometer which is briefly described in Article 183, the needle and its pair of quadrants may be connected to earth and the other pair of quadrants to the charged body. Then, if the instrument is sufficiently sensitive, the needle will be deflected an amount which is proportional to the difference between the earth's electrical pressure and that of the charged body, or between the two plates of the condenser.

**190. Specific Inductive Capacity.** — The capacity of a condenser depends directly upon the area of its plates, their closeness together, and the **Specific Inductive Capacity** of the dielectric.[2] Different insulating materials have very different values as dielectrics. The inductive action seems to be stronger through some materials than through others, and it is less active through air than through any solids or liquids. Consequently a condenser which has air for a dielectric has less capacity than one of exactly equal size with a solid dielectric. The ratio of the capacities of two such condensers, in which the dielectric of one is air, is called the *specific inductive capacity* of the solid dielectric. The annexed table gives the approximate specific inductive capacities of various materials. That of air is taken as unity as a matter of reference, because the inductive effect is less through it than through any common substance.

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[1] Article 17.

[2] Article 26.

| MATERIAL | SPECIFIC INDUCTIVE CAPACITY | MATERIAL | SPECIFIC INDUCTIVE CAPACITY |
|---|---|---|---|
| Air . . . . . . . | 1. | Gutta-percha . . | 2.5 |
| Petroleum . . . . | 2.1 | Shellac . . . . . | 2.9 |
| Turpentine . . . . | 2.2 | Sulphur . . . . | 3.7 |
| Rubber . . . . . | 2.3 | Mica . . . . . | 6.6 |
| Paraffine . . . . . | 2.3 | Glass . . . . . | 5.00 to 10.00 |

The table shows the importance of carefully selecting the insulation for telephone cables where capacity is very objectionable. In fact, the insulation directly surrounding the individual wires of such cables is often made from crinkled paper, so that air makes up a considerable part of the material between the wires. While glass is one of the best insulators, it is one of the poorest materials to use for the continuous insulation of wires in telephone cables on account of its great specific inductive capacity.

Insulated wires and cables placed underground always have a much greater capacity than wires of the same size and length placed overhead. This is largely because the dielectric of the underground wires is so much thinner than that of the overhead wires, and partially because the inductive capacity of solid dielectrics is greater than that of air. The capacity of an overhead wire, strung at a height of 30 feet above the ground, is only about one-twentieth of that of a similar wire well insulated with a rubber compound and placed underground, and only about one-tenth of that of a similar wire insulated with cotton and paraffine and placed in a cable underground.

**191. Relation of Pressure, Charge, and Capacity in a Condenser.** — It was stated in Article 28, that a condenser of one farad capacity holds opposite charges of one coulomb on its two plates whenever they differ in pressure by one volt. If one volt charges it with two coulombs, the capacity is two farads; if with three coulombs, three farads, and so on. Or we may say that *when the pressure is constant, the quantity of charge is directly proportional to the capacity*. Also, *if the capacity is fixed, the quantity of the charge is proportional to the pressure*. These two statements together show *that the electrical charge of a condenser varies directly with the capacity and also directly with the pressure.*

This may be written in symbols, $S' = \frac{Q}{E}$, where $S'$ is capacity in farads, $Q$ quantity on each plate in coulombs, and $E$ pressure in volts. Since a microfarad is one millionth of a farad we may also write $S = 1{,}000{,}000\frac{Q}{E}$, where $S$ is the capacity in microfarads.

This relation may be compared to the capacities of water tanks. If a tank of "unit capacity" is assumed as one in which the water has a height of one foot when charged with one gallon, then the greater the number of gallons required to raise the water level one foot the greater is the capacity; and also with a tank of given capacity, the quantity of water in the tank depends upon the height. The quantity of water in a tank therefore varies directly with the "capacity" of the tank, and also directly with the height that it stands in the tank.

## PROBLEMS

*A.* A condenser is charged with .00001 of a coulomb of electricity when its terminals are at a difference of potential of 10 volts. What is its capacity? *Ans.* 1 microfarad.

*B.* A condenser of .5 microfarad capacity is charged by a difference of potential of 100 volts. What is the quantity of the charge? *Ans.* .00005 coulomb.

*C.* What pressure is required to charge a .2 microfarad condenser with a charge of .0001 coulomb? *Ans.* 500 volts.

*D.* If one condenser holds four times as much electricity when charged by 50 volts as does another when charged by 100 volts, what is the ratio of the capacity of the first condenser to that of the second? *Ans.* 8.

**191 *a*. Condensers in Series and Parallel.** — Since the capacity of a condenser is directly proportional to the area of the plates,[1] *connecting condensers in parallel gives a total or combined capacity which is equal to the sum of the individual capacities.* Again, since the capacity depends inversely upon the thickness of the dielectric,[2] *connecting condensers of equal capacity in series gives a combined capacity equal to the capacity of one condenser divided by the number in series*, because connecting condensers in series has the effect of adding together the thicknesses of the dielectrics in the different condensers. *Where condensers of different capacities are connected together in series, the com-*

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[1] Article 190.

[2] *Ibid.*

*bined capacity is equal to the reciprocal of the sum of the reciprocals of the individual capacities.* $\left(\frac{1}{S}=\frac{1}{S_1}+\frac{1}{S_2}+\frac{1}{S_3}\right)$.[1] Condensers connected in series are sometimes said to be connected in **Cascade.**

The plates of standard condensers are usually made of tinfoil, and the dielectric of mica, paraffined paper, or oiled paper.

### PROBLEMS

*A.* If three $\frac{1}{2}$ microfarad condensers are connected in parallel, what is their combined capacity? *Ans.* $1\frac{1}{2}$ microfarads.

*B.* Suppose four condensers of $\frac{1}{4}$, $\frac{1}{2}$, 1, and $1\frac{1}{2}$ microfarads capacity are connected in parallel, what is their combined capacity? *Ans.* $3\frac{1}{4}$ microfarads.

*C.* If the condensers of Example *A* are connected in series, what is their combined capacity? *Ans.* $\frac{1}{6}$ microfarad.

*D.* If the condensers of Example *B* are connected in series, what is their combined capacity? *Ans.* $\frac{3}{23}$ microfarad.

*E.* If you have three condensers of $\frac{1}{2}$, $\frac{1}{4}$, and 1 microfarad capacity, respectively, what are the various values in microfarads besides the individual values that you can have at your disposal for testing purposes, using them in all combinations?

1st, Parallels of 3 and 2. *Ans.* $1\frac{3}{4}$, $1\frac{1}{2}$, $1\frac{1}{4}$, $\frac{3}{4}$.
2d, Series of 3 and 2. *Ans.* $\frac{1}{7}$, $\frac{1}{6}$, $\frac{1}{5}$, $\frac{1}{3}$.
3d, Series parallel. *Ans.* $1\frac{1}{6}$, $\frac{7}{10}$, $\frac{7}{12}$, $\frac{6}{14}$, $\frac{5}{14}$, $\frac{8}{14}$.

**192. Standard Condensers.** — Standard condensers are made of various capacities and put up in boxes so that they may be readily used for various purposes. Since a capacity as large as a farad is really never met in the electrical industries, standard condensers are usually made equal to **Microfarads**[2] (one-millionths of a farad) or fractions of microfarads, and the microfarad has become the common unit in which capacities are measured. Figure 111 shows an adjustable condenser which is made with five divisions of .1 microfarad each.

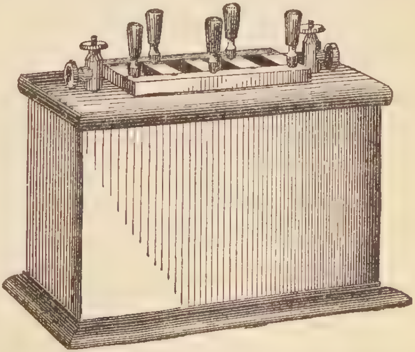

FIG. 111. Standard Half Microfarad Condenser Box.

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[1] Compare combined resistances, Articles 102, 103, and 104.

[2] Article 28.

The five divisions may be put in parallel so that the total capacity is $\frac{1}{2}$ microfarad. Figure 112 illustrates diagrammatically the connections of the condensers to the brass blocks on top of the box. Figure 113 shows the way in which the condensers are made up of alternate plates of tinfoil and oiled paper.

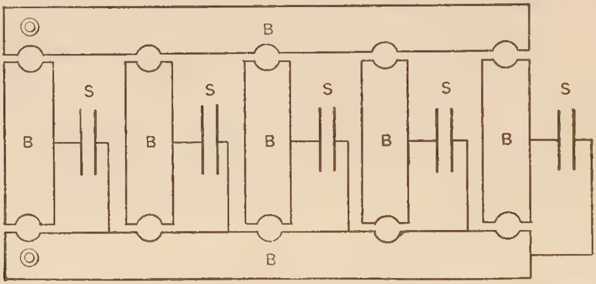

FIG. 112. — Diagram of the Connections of Condenser Sections in Standard Box. *S*, *S*, *S*, are the Condenser Sections and *B*, *B*, *B*, are Brass Blocks.

**193. Measurement of Capacity by Ballistic Galvanometer.** — It is very important to make measurements of the capacity of conductors to be used in telephony and telegraphy. This may be done in various ways, but the method generally used is to compare the capacity of the wire directly with that of a standard condenser by means of a **Ballistic Galvanometer.**

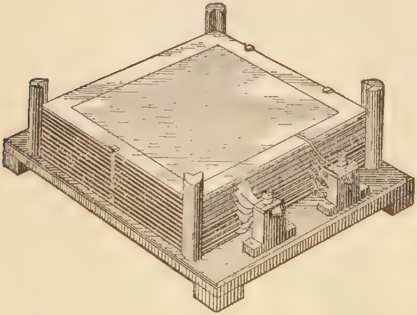

FIG. 113. — Illustration of the Construction of a Condenser.

A ballistic galvanometer is simply a sensitive galvanometer which is not dead-beat. In this case, if a certain quantity of electricity is caused to pass through the coils of the instrument in a very short interval of time, its magnetic effect on the needle is very much like that of a blow, while the magnetic effect of a steady current is like that of a steady push on the needle. The needle of a galvanometer, when such a **Transient Current** or **Discharge** passes through it, swings off through an angle which is proportional to the quantity of electricity in the discharge, provided the angle of swing or **Throw** is not too great.

To measure the capacity of a cable, a standard condenser is selected of a capacity nearly equal to that of the cable. The condenser is charged by a battery of a few cells, and by means of a key its connections are then changed so that it discharges through a galvanometer. The throw of the galvanometer needle (distance it swings) is observed. The same battery is now connected with one terminal to the cable conductor, and its other terminal to the cable sheathing or to the earth. In this way the cable is charged. The cable and earth connections are then transferred to the galvanometer by means of the key, and the cable is discharged through the galvanometer. The throw of the needle is again observed. The two throws are proportional to the quantities of electricity in the charges of the condenser and the cable. Since these were charged by the same battery and therefore to the same pressure, the quantities of electricities are proportional to the respective capacities. Therefore, the capacities are proportional to the throws.

The object of taking a condenser of a capacity nearly equal to that of the cable is to make the throws nearly alike, and thus avoid instrumental errors. When a proper condenser cannot be obtained, a shunt may be applied to the galvanometer, but this is also likely to introduce errors when used with discharges. The insulation of the instruments and their connections must be as perfect as possible in capacity tests, as is also necessary in insulation tests.[1]

As an example, suppose the discharge of a $\frac{1}{2}$ microfarad condenser when charged by five cells gives a galvanometer throw of 200 divisions; and when a cable two miles long is charged by the same cells, and discharged through the galvanometer, the throw is 180. Then the capacity of the cable is $\frac{180}{200} \times \frac{1}{2} = .45$ microfarads, and the capacity of the cable per mile is $.45 \div 2 = .225$ microfarads.

It is usual to speak of the "capacity of a wire" or of a cable in the manner of the preceding paragraphs, but it must not be forgotten that the conductor of the cable is only one plate of the condenser. The other plate consists of the return conductor through which the working electric circuit is completed, such as the earth, the cable sheathing, or another wire, while the dielectric of the condenser is the intervening insulation. And the "capacity of a cable" is therefore the capacity of the condenser in which the cable conductor constitutes one plate and the insulation of the conductor constitutes the dielectric.

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[1] Articles 169 and 170.

## PROBLEMS

*A.* A condenser of .2 microfarad capacity, charged to 10 volts difference of potential, causes a throw of 150 divisions when it is discharged through a galvanometer. A certain cable one mile long causes a throw of 75 divisions when charged by the same difference of potential. What is the capacity of the cable? *Ans.* .1 microfarad.

*B.* A condenser of .3 microfarad and a piece of cable cause the same throw in a galvanometer when the former has been discharged after having been charged by 10 volts difference of potential and the latter by 20 volts. What is the capacity of the cable? (Aid: The galvanometer needle would be deflected only half as far if the cable were charged to 10 volts.) *Ans.* .15 microfarad.

*C.* An overhead telegraph line, after having been charged to 100 volts, gives a throw on the galvanometer of 50 divisions when it is discharged. The same galvanometer will deflect 100 divisions when a 1 microfarad condenser charged to 5 volts is discharged through it. What is the capacity of the line? (Aid: The galvanometer would deflect 2.5 divisions if the line were charged to 5 volts.) *Ans.* .025 microfarad.

**194. Electrical Units.** — The following table gives a review of the units that have been explained in this and the preceding chapters: —

Ampere = unit of current.
Milliampere = one-thousandth of an ampere.
Microampere = one-millionth of an ampere.
Volt = unit of pressure.
Millivolt = one-thousandth of a volt.
Microvolt = one-millionth of a volt.
Ohm = unit of resistance.
Megohm = 1,000,000 ohms.
Coulomb = unit of quantity.
Farad = unit of capacity.
Microfarad = one-millionth of a farad.
Watt = unit of power.
Kilowatt = 1000 watts.
Horse power = 746 watts.
Joule = unit of work = one watt second.
Watt hour = unit of work = 3600 watt seconds.
Kilowatt hour = 1000 watt hours.
Horse power hour (H. P. H.) = 746 watt hours.

The prefixes micro, milli, kilo, and meg (or mega), which respectively mean one-millionth, one-thousandth, one thousand, and one million, may be applied to any of the electrical units. For instance, one kilovolt means one thousand volts, one microhm means one-millionth of an ohm, etc.

## QUESTIONS

1. How can the power in a direct current circuit be measured by means of an amperemeter and a voltmeter?
2. What is a wattmeter?
3. How can an electrodynamometer be arranged for use as a wattmeter?
4. How would you connect a wattmeter to measure the power used by a bank of incandescent lamps in parallel?
5. What would happen if the current coil of a wattmeter was connected into a circuit where the pressure coil should be?
6. What is a recording wattmeter?
7. What is a watt hour?
8. Describe a Thomson recording wattmeter.
9. What is the principle of the retarding device in the Thomson wattmeter?
10. What is an ampere hour?
11. Why cannot the difference of pressure between an insulated charged body and the earth be measured by an ordinary voltmeter?
12. How should an electrostatic voltmeter be connected up to measure the pressure of a charged body?
13. What is "specific inductive capacity"?
14. Of the common materials, which has the least inductive capacity?
15. What are the numerical values of the specific inductive capacities of gutta-percha and glass?
16. Why is crinkled paper better than rubber for insulating telephone cables?
17. Why have wires placed under ground a greater capacity than the same wires if placed overhead?
18. What is a microfarad?
19. How are standard condensers made?
20. What is the combined capacity of condensers connected in parallel?
21. What is the combined capacity of equal condensers connected in series?
22. What is the combined capacity of unequal condensers connected in series?
23. When are condensers connected in cascade?
24. What are standard condenser plates and dielectrics commonly made of?
25. What is a ballistic galvanometer?
26. What is the "throw" of a galvanometer?
27. If a ballistic galvanometer having poor insulation were used in capacity measurements, what would happen?
28. Name the various electrical units that you have become acquainted with.

# CHAPTER XV

## PRINCIPLES AND CONSTRUCTION OF DIRECT CURRENT DYNAMOS AND MOTORS

**195. Direct Current Dynamos.** — A dynamo consists essentially of a machine for transforming mechanical energy into electrical energy, or *vice versa*, through the intervention of electromagnetic induction. As already stated in an earlier chapter,[1] Faraday discovered, about 1830, that a conductor cutting lines of force, when part of a closed circuit, will produce a current. He then constructed crude machines for utilizing this phenomenon, and he may, therefore, be fairly considered to be the primary inventor of the dynamo. During the following years many investigators, some of whose names are famous, entered this fascinating field of discovery; and within a very few years they displaced the permanent magnet for furnishing the magnetic field by the electromagnet, built up the armature cores of laminations, constructed commutators, and used more than one pair of poles. During the decade of the fifties, Siemens, Gramme, and Pacinotti appeared with improvements which developed the dynamo into nearly its present form, but minor improvements have been and are being continually perfected.

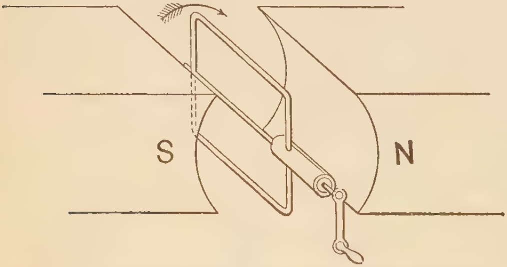

FIG. 114. — Coil arranged to be rotated in Magnetic Field.

**196. Single Coil Dynamo.** — If a coil is mounted on an axis or shaft, so that it may be *revolved in a magnetic field* (Fig. 114), a condition exists which is described in the last paragraph of Article 136, and an alternating current is produced in the coil when it is revolved.

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[1] Article 132.

If, instead of being short-circuited on itself, the coil is connected to an external circuit by means of such sliding contacts as are shown in Figure 115, the alternating current may be led off to be used for any desired purpose. The rings *AA*, to which the ends of the coils are attached, in this case are called **Collecting Rings** or **Collectors**, and the parts *BB*, which bear on the collectors, are called **Brushes**. In an actual machine made up for the purpose of generating electricity by a coil revolving in a magnetic field, the revolving part is called an **Armature**. Telephone **Magnetos**, which are used for ringing telephone call bells, consist of a coil of wire wound on an iron core, which is revolved in the magnetic field between the poles of a permanent horseshoe magnet (Fig. 116). An enlarged cross section of the armature is shown alongside of the complete machine in Figure 116. Such machines produce alternating currents.

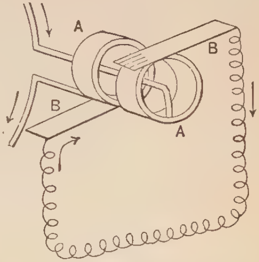

FIG. 115.—Ends of Coil connected to Sliding Rings, *AA*, with Brushes, *BB*, making Connection with External Circuit.

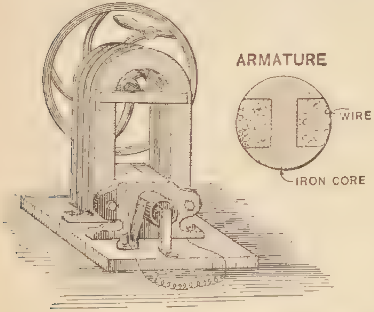

FIG. 116.—Magneto Generator of Alternating Currents.

**197. Commutators.**—It is possible to arrange the collector which is attached to a coil that is revolved in a magnetic field in the manner shown in Figure 117. With this arrangement, the collector segments connect each brush first with one end of the coil and then with the other end as the coil revolves. If the brushes are properly **Set** (that is, if they bear on the collector at proper points), this arrangement causes the current to flow continuously in one direction in the external circuit, though in the coil itself, the direction of current flow reverses with each half revolution as before. Such an arrangement of the collector is called a **Commutator**, and the current in the outside circuit is said to be **Commutated** or **Rectified**. The *brushes must be set on opposite sides of the commutator and between the pole tips*, otherwise little or no current will be sent into the external wire and much sparking may result. Figure 118 shows one of the early dynamos with a single coil armature and commutator of two segments. This machine looks quite like the magneto shown in Figure 116, but the collector is different, and the magnetic field is set up by an electromagnet instead of a permanent magnet.

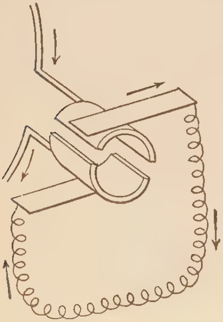

FIG. 117.— Collector with Two Segments.

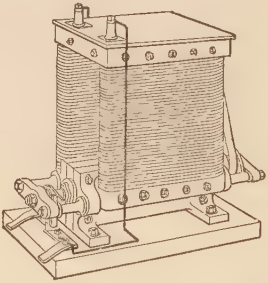

FIG. 118.—Old Style Small Dynamo.

**198. Current Wave in a One-coil Armature.** — An armature with one coil and a two part commutator furnishes a current consisting of a series of waves, or pulsations, which may be represented by Figure 119. This is easily understood after a little consideration. When the coil stands up and down between the pole pieces as in Figure 114 and the full lines in Figure 120, it is in such a position that when it is revolved a small amount, the conductors move practically parallel to the lines of force and no lines are cut. When the coil is in continuous revolution, no pressure is induced at the instant that it is in the positions shown in Figure 114 and the full lines in Figure 120, which correspond with the points *A*, *C*, and *A'* in Figure 119.

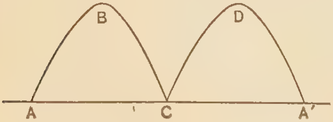

FIG. 119.— Diagram of Current Pulsations.

When the coil stands as shown by the dotted lines in Figure 120, it is in such a position that the conductors cut squarely across the lines of force as they move, and the largest possible number of lines of force are cut for a given amount of motion. The dotted position of the coil shown in the figure and the position 180° therefrom correspond with the points *B* and *D* in Figure 119.

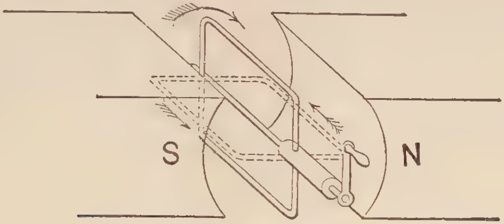

FIG. 120. — Coil arranged to be rotated in Magnetic Field.

## PROBLEMS.

*A*. Suppose we have a single coil armature of 20 turns in a magnetic field of such strength that each conductor cuts 1,000,000 lines in each half-revolution. If the machine runs at 1500 revolutions per minute, what is the average pressure developed? (Aid: Each conductor cuts 2,000,000 lines in a revolution, but each turn has two cutting conductors. Therefore each turn will cut 4,000,000 lines in each revolution. Twenty turns give an effect twenty times as great, which is equivalent to cutting 80,000,000 lines per revolution by one turn. The armature makes $1500 \div 60 = 25$ revolutions per second, hence the coil gives the effect of cutting $25 \times 80{,}000{,}000$ lines per second. This is equal to 2,000,000,000 lines cut per second. But to create a pressure of one volt requires that 100,000,000 lines be cut per second.[1] Therefore the machine will develop $\frac{2000000000}{100000000} = 20$ volts.)

*B*. Suppose we have a single coil armature of 50 turns in a field of such strength that each conductor cuts 2,000,000 lines of force per each half-revolution. If the speed is 1200 revolutions per minute, what is the average pressure developed? *Ans.* 80 volts.

**199. Armatures having More than One Coil; Gramme Ring.** — Direct current dynamos having armatures with one coil are not satisfactory for general use for two reasons: —

1. The wavy character of the current is a disadvantage for some purposes.

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[1] Article 134.

2. The commutation of large currents at the full pressure which is required for most commercial uses is not practical.

To overcome these difficulties coils must be uniformly distributed over the surface of the armature, and the windings must be connected at equal intervals to commutator segments. The first armature of this kind that was put into commercial service was invented in 1870 by a Frenchman named Gramme. The core of Gramme's armature consisted of a ring made of iron wire. This ring had a winding made of insulated copper wire wound uniformly over its surface, and at equal intervals the windings were electrically connected to commutator segments. The arrangement is shown in Figure 121. When this armature is placed in a magnetic field, the lines of force pass through the iron armature core from one pole to another in the way that is illustrated in Figure 122, so that the revolution of the ring *causes the outer conductors to cut lines of force*, but the inner conductors are entirely shielded.

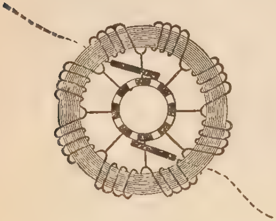

FIG. 121. — Gramme Armature.

When the armature is revolved, the wires of the armature winding which are under one pole piece cut lines of force in one direction, and those under the other pole piece cut lines in the opposite direction. The effect of the opposing electric pressures which are thus set up in the windings of the armatures, is to cause a point at one side of the armature to come to a high electrical pressure and a point on the opposite side to come to a low electrical pressure.

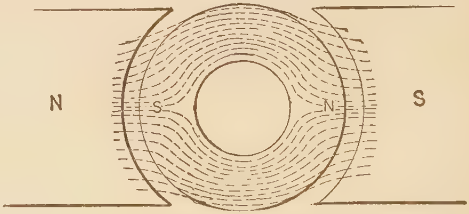

FIG. 122. — Illustration of Way in which Magnetism passes through Gramme Armature Core.

If brushes bear on the commutator at these points (*A* and *B* in Fig. 123), a current flows in the external circuit from the high to the low pressure side of the armature, that is, from A to B. The path of the current through the armature itself is from B to A, *through the two* *halves of the armature in parallel.* This is plainly shown by the figure.

Since the number of conductors under the pole pieces is practically the same for every position of the armature during the revolution, the armature produces a practically uniform pressure when it is continuously revolved at a uniform rate, as when it is driven by a steam engine.

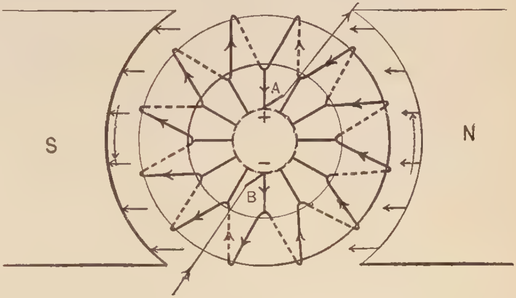

FIG. 123.—Gramme Armature, showing the way in which Current flows through it.

As a rule, commercial **Gramme** or **Ring Armatures** are not wound with a continuous wire, but the divisions of the armature windings, the ends of which are connected to adjacent **Commutator Segments** or **Bars**, are wound as separate coils. This makes it possible to insulate the different parts of the winding more effectively from each other, and thus prevent the current from jumping by a short path, or **Short-circuiting**, directly from one coil to another, instead of following all the way around the coils. The separate coils are connected to the commutator segments, and to each other, in such a way that the winding is in effect the same as though made with a continuous wire connected at intervals to the commutator segments.

## PROBLEMS

*A.* A Gramme armature has 50 coils of 5 turns each. Two million lines of force pass through this armature. If the speed is 600 revolutions per minute (equal to 10 revolutions per second), what pressure is developed? (Aid: In a Gramme armature there is one cutting conductor per turn. Each conductor cuts the two million lines twice in a revolution, and the total number of lines cut per revolution by all the conductors is therefore 1,000,000,000. If all the coils worked in series, the pressure would be 100 volts, but since this pressure is divided into two paths in parallel, the pressure between the brushes is 50 volts.) *Ans.* 50 volts.

*B.* A Gramme armature has 60 coils of two turns each. Five million lines of force pass through the armature. If the speed is 900 revolutions per minute, what pressure is set up? *Ans.* 90 volts.

*C.* A Gramme armature as in Example *A* revolves 1200 revolutions per minute. If it is to set up 100 volts, how many lines of force must there be in the field? *Ans.* 2,000,000.

*D.* Suppose the armature of Example *B* was to develop 45 volts, how many turns would the armature need to carry if the speed and field were not changed? *Ans.* 60.

**200. Drum Armatures.** — The armature core may be an iron cylinder or drum, made out of disks of sheet iron laid together (Fig. 124), instead of an iron ring. In this case the winding seems more complicated, but its general plan is similar to that of the ring armature. The winding consists of a number of coils wound uniformly over the surface of the drum, which are connected together in such a way that *the winding is electrically the same as though it had been made with a single long wire.* The coils are connected to the commutator bars exactly as in the ring armature, and their effect in producing electrical pressure when the armature is revolved is just the same as has already been explained in the case of the ring armature. Armatures with drum-shaped cores are called **Siemens** or **Drum Armatures.**

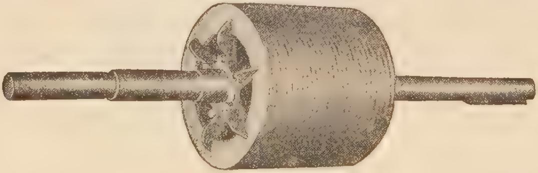

FIG. 124. — Drum Armature Core, showing its Laminated Character.

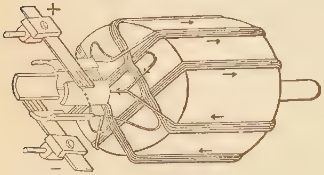

FIG. 125. — Drum Armature with Four Coils and Commutator of Four Segments.

A Siemens armature with four coils is shown in Figure 125, from which may be seen the way in which the wires are wound on the core and connected to the commutator. It is seen from this figure that both sides of the coil cut lines of force in a drum armature, but as they are under opposite poles the current in one side tends to go toward the back and the other toward the front of the armature. It is, therefore, evident that the pressures in the conductors on the two sides of an armature add together to cause the current to circulate properly through the coils. Arrows indicating the relative directions are shown in the figure. Figure 126 shows one coil wound upon an armature core which is intended for sixteen coils. The armatures of commercial dynamos usually have from thirty to one hundred coils.

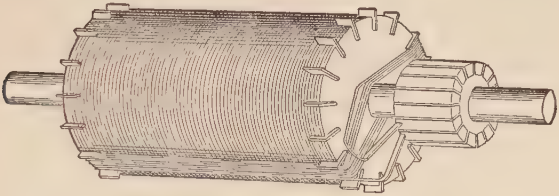

FIG. 126.—Drum Armature Core with Commutator of Sixteen Segments, showing One Coil wound on the Core.

### PROBLEMS

*A.* A Siemens armature has 25 coils of five turns each. Two million lines of force pass through the armature. If the speed is 600 revolutions per minute, what will be the pressure developed? (Aid: In a drum armature each turn has two cutting conductors, so that the total number will be the same as in Example *A*, Article 199.) *Ans.* 50 volts.

*B.* A Siemens armature is to develop 100 volts in a field having 4,000,000 lines of force. How many turns (two conductors to the turn) must the armature bear if the speed is to be 1500 revolutions per minute? *Ans.* 50 turns.

**201. Core Laminations; Eddy Currents.** — It has already been said that the early Gramme armature **Cores** were made out of iron wire coiled up to form a ring. In modern machines the cores for both Gramme and Siemens armatures are built up of disks, which are punched out of sheet iron (Fig. 124). These disks are usually insulated from each other by thin tissue paper, or by thin coverings of varnish or non-conducting oxide. The object of dividing the cores into disks, or **Laminating** them, and of insulating the disks from each other, is to prevent currents from being set up in the core itself when it is revolved in the magnetic field. The rule that electric pressures are set up when a conductor cuts lines of force applies equally as much to the core of the armature as to the windings. Currents tend to flow in armature cores from one end to the other near the surface under one magnet pole, and to return under the opposite pole. By properly laminating the cores, these currents are nearly all prevented, while the passage of lines of force through the iron, from one side of the core to the other, is not interfered with.

The great objection to permitting currents to circulate in the armature core is the fact that it takes power to keep them circulating, and all this power is converted into heat in the armature core, and is wasted. The heating of the core has another disadvantage, since a high temperature is likely to injure the cotton and shellac insulation which is used between the coils themselves, and between the coils and core. Even with the best of **Lamination** a certain amount of power is lost, and heating is caused, by currents circulating in the core disks. These currents are ordinarily called **Eddy Currents**, because they eddy uselessly through the core, or **Foucault Currents**, after the name of a scientist who made some investigations many years ago relating to the generation of currents in masses of metal.

**202. Hysteresis Loss.** — There is an additional cause of lost power and heating in the cores of armatures which cannot be reduced by lamination. This seems to be due to a sort of friction between the molecules as they are caused to turn over by the attraction of the magnetic field while the armature revolves. Every time the molecules are caused to turn around under the influence of a magnetic field, a certain amount of power is used, which is converted into heat; consequently, for every revolution of the armature, a certain amount of power is used, and converted into heat. This effect is another result of the phenomenon of magnetism which is called **Hysteresis**, and which is described in Article 128.

The amount of power wasted and heat produced in a core on account of hysteresis depends upon the amount of iron in the core, the number of revolutions made by it in a minute, the density of magnetism in the iron, and the quality of the iron. It may be said that, in general, the softer the iron the less is the loss due to hysteresis; consequently, the iron used in armature cores is very soft wrought iron or steel which has been carefully annealed.

**203. Field Magnets.** — The magnetic field in which the armature revolves is ordinarily produced by a great electromagnet. The frame of this electromagnet is so arranged that it can hold the windings required to set up the lines of force; and in order that the lines may be caused to pass through the armature, the poles are arranged to embrace the armature. These expanded poles are called **Pole-pieces** (*PP* in Figs. 127 and 128), and the whole of the magnet frame is called the **Field** of the machine. The parts of the field upon which the windings are placed are often called the field **Cores** (*mm*, in Figs. 127 and 128). The portion of the magnet that connects the cores is called the **Yoke** (*y* in Figs. 127 and 128).

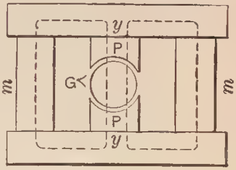

FIG. 127. — Diagram of Dynamo Frame.

**204. Air Space.** — It is always necessary to allow a certain amount of space between the pole-pieces and the surface of the armature, and in addition a certain amount of space is occupied by the armature windings, so that a considerable depth of non-magnetic material exists between the iron of the pole-pieces and the iron of the armature core. This space is usually called the **Air Space** or **Gap** (*G*, Figs. 127 and 128).

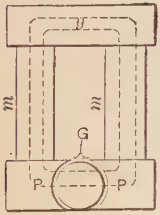

FIG. 128. — Diagram of Dynamo Frame.

**205. Reluctance of Magnetic Circuit.** — The number of ampere turns, which are required to give the magnetomotive force that is needed to set up the lines of force necessary to induce a given electrical pressure in the armature windings, depends upon the reluctance of the armature core, of the air gap, and of the magnet frame. Since there is no insulator of magnetism, some of the lines of force which are set up in the field will leak around the armature instead of passing through it, and the cross section of iron in the path of the lines of force through the field must be sufficiently large to hold these leakage lines as well as the useful ones which pass through the armature. It is the **Leakage**, or stray lines of force, which magnetize watches when they are carried near a dynamo.

In order that the proportion of the total number of lines of force that leak around the armature shall be as small as possible, the reluctance of the air gap, which is always a considerable part of the total reluctance in the magnetic circuit, must be made as small as possible.

### PROBLEMS

*A.* The reluctance of the magnetic circuit of a dynamo is .002. How many ampere turns will be required to create a field of 4,000,000 lines?[1]

(Aid: Apply formula $N = \frac{1.257\,nc}{P}$ or $nc = \frac{NP}{1.257}$.[2]) *Ans.* 6360 (approx.).

*B.* The reluctances of the parts of the magnetic circuit of a certain dynamo are calculated to be as follows: Yoke, .0001; field cores, .0002; pole pieces, .0002; armature, .00075; and air spaces, .00155. How many ampere turns are required to set up a field of 2,000,000 lines of force? (Aid: Add the reluctances together, since they are in series.) *Ans.* 4460 (approx.).

*C.* The magnetic circuit of a dynamo has a reluctance of .004. The armature of the dynamo requires 2,000,000 lines of force to set up its normal pressure. If the magnet coils are to have 2 amperes passed through them, how many turns must they have? *Ans.* 3180 (approx.).

*D.* If the pressure supplied by the dynamo to the field coils of Example *C* is 100 volts, what must be the resistance of the coils? *Ans.* 50 ohms.

**206. Toothed Armatures.** — It is also of advantage to make the air gap reluctance, and therefore the total reluctance of the magnetic circuit, as small as possible, because the number of ampere turns which are required to set up the field magnetism are thereby reduced, and the expense of building the machine is consequently decreased. For this purpose, the armature core is often made *toothed*, and the

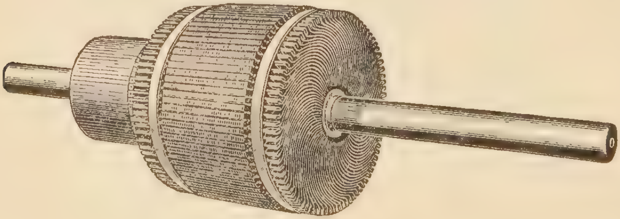

FIG. 129. — Complete Armature with a "Toothed" or "Slotted" Core.

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[1] Magnetic leakage is not considered in these problems.

[2] Article 131.

windings are placed in the slots or grooves between the teeth (Fig. 129).

It is sometimes thought that placing the armature conductors in grooves between teeth in the core permits some of the lines of force to pass through the core in such a way that they are not cut by the conductors as the armature revolves. This is a mistake, however, and an armature with the conductors wound in slots gives exactly the same electrical pressure when revolved in a magnetic field as is given by an armature with the same number of conductors wound on the surface of its core when it is revolved at the same speed in a field of the same strength.

## QUESTIONS

1. What had Faraday to do with development of the dynamo?
2. Give a brief history of the development of the dynamo.
3. What is the action of a single coil dynamo?
4. Is the slider arrangement described in Art. 134 a dynamo in principle?
5. What are collecting rings?
6. What are dynamo brushes?
7. What is a dynamo armature?
8. What is a magneto?
9. What is a commutator?
10. How does a commutator act?
11. What is a rectified current?
12. Where must the brushes be set on the commutator?
13. What is the form of the rectified current delivered from a one-coil armature?
14. Why are not one-coil armatures used commercially?
15. Who invented the first commercially used many-coiled armature? When?
16. How is a Gramme armature wound?
17. How does the current flow through a Gramme armature?
18. Why are there two parallel paths for the current in a Gramme armature?
19. Why does a many-coiled armature produce a practically constant pressure?
20. What is a commutator bar?
21. What is a Siemens armature?
22. How is a Siemens armature wound?
23. Compare drum and ring windings.
24. Why do the pressures set up on the two sides of a drum armature coil add together?
25. What is the armature core? Why is it made of iron?
26. How are armature cores made?

27. Why are armature cores laminated?
28. What are Foucault or eddy currents?
29. Why are Foucault currents disadvantageous in the core of an armature?
30. What effect has hysteresis in an armature core?
31. What does the hysteresis loss depend upon?
32. How are dynamo field magnets made?
33. What is the field of a dynamo?
34. What are the pole-pieces? The yoke? The field core? The air gap?
35. Should the reluctance of a dynamo field be great or small?
36. What effect has the quality of iron and length of air gap on the field reluctance?
37. Why is a watch likely to be magnetized when brought near a dynamo?
38. What is magnetic leakage?
39. What effect has the length of the air gap upon magnetic leakage?
40. What is a toothed armature?
41. What advantages have toothed armatures?
42. Will a toothed armature give any less pressure than a smooth one?

**207. Electric Motors.** — We have seen that the operation of dynamos is a direct application of Faraday's discovery, that an *electrical pressure is generated in a conductor when it is moved in a magnetic field.*

Electric motors work on the principle that a *conductor carrying a current tends to move when placed in a magnetic field*, on account of the mutual action of the lines of force of the field and of the current. The reasons for these actions we do not know, but we know of their existence as the result of experiment, and are able to apply their results to practical use.

These two principles are practically the reverse of each other, and the action of generators and motors is, therefore, a **Reversible** one. That is, a machine which is designed to be used as a dynamo to generate electric currents when driven by mechanical power, may usually be used equally well to generate mechanical power when driven as a motor by electric currents. It is a fact that the machines that are the best generators also usually make the best motors; and manufacturers sell their standard direct current dynamos, to be used either as generators or motors. We shall, therefore, treat them as entirely similar in construction. It is only when the machines are built to be used for some special purpose that they cannot be conveniently interchanged in their action.

When the motor armature is caused to revolve by the magnetic attractions, its conductors cut the lines of force of the field, and *an electric pressure is, therefore, set up in them*, just as has been described in the early articles of this chapter. The direction of this is opposite to that of the external source which sends the current through the armature. The electric pressure which is thus set up in the armature conductors of the motor is called a *counter electric pressure*, or *counter electromotive force.*

*The work which is done by the motor is dependent upon this counter electric pressure, and a useful electric motor which does not produce a counter electric pressure, is as impossible of existence as is a perpetual motion machine.* Seekers after either are looking for the impossible.

When a dynamo armature is revolved in a magnetic field so as to produce a current, the lines of force belonging to the current are attracted by the lines of force belonging to the field. This attraction tends to stop the motion, so that power has to be exerted to keep the armature moving. The greater the current the greater must be the pull or **Torque** given to the dynamo pulley to make it rotate. Likewise, in a motor, the current flowing in the armature must be sufficient to give the necessary pull to keep the armature going, whatever the load upon the motor pulley. By Ohm's Law, the amount of current that will flow through the resistance of the armature will be proportional to the pressure. In a motor, the pressure sending currents through the armature windings is the difference between the pressure applied to the armature and the counter pressure. Evidently, then, when a load is put on the pulley, the motor armature must either slacken a little in speed, or the fields must be weakened, to so reduce the counter pressure that sufficient current will flow through the armature windings and give the proper torque.

This is a general rule for dynamos: *The greater the mechanical work the greater must be the electric work, or vice versa.*

**208. Machine Efficiency.** — The electrical power delivered by a dynamo to the circuit with which it is connected is always less than the mechanical power used in driving the machine. The difference is absorbed in the machine itself, and is transformed into heat which warms the dynamo, through the effects of friction, hysteresis, eddy currents, and the $C^2R$ loss in the dynamo windings.

If this difference is great, — that is, if the internal **Losses are great,** — the dynamo may not be a satisfactory one, and we say its **Efficiency** is low. The actual value of the efficiency is found through dividing the number of watts delivered to the circuit by the dynamo, by the number of watts representing the mechanical power used in driving the machine. In other words, *the efficiency is equal to the ratio of the power taken out of a machine to the power put in.* This definition applies to all classes of machinery.

When a machine is caused to operate as a motor by furnishing current to it from an external source, the same losses exist, so that the amount of electrical power which must be furnished to it is greater than the mechanical power which is taken from its pulley.

## PROBLEMS

*A.* If 25 horse power are used in driving a dynamo of 15 kilowatts capacity when it is furnishing its full capacity to the external circuit, what is its full load efficiency? (Aid: Reduce all power to watts.) *Ans.* 80.4% (approx.).

*B.* A motor requires 10 kilowatts to enable it to supply its full capacity of 10 horse power to its pulley. What is its full load efficiency? *Ans.* 74.6 per cent.

*C.* The motor of Example *B* will have essentially the same efficiency when driven as a dynamo. If it gives to the external circuit 7460 watts when running as a dynamo at full load, how many horse power will be required to drive it? *Ans.* 13.4 H. P. (approx.).

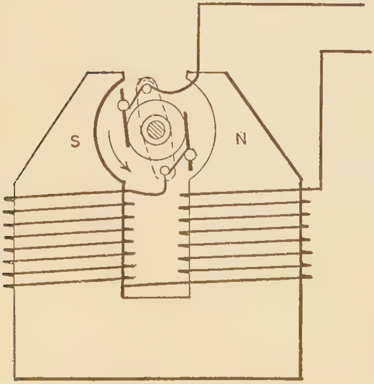

FIG. 130. — Diagram of Series-wound Dynamo.

**209. Series, Shunt, and Compound Wound Dynamos and Fields.** — The exciting current for the fields of a dynamo is almost universally generated by the machine itself, the pressure at starting being obtained by the slight residual magnetism that remains in the magnets. In order to distinguish the several methods of winding the fields, dynamos may be divided into three classes. These are: —

1. **Series-wound** (Fig. 130), in which the field winding is connected in series with the external circuit, and all the current generated by the dynamo passes through a thick wire which is wound a comparatively few times around the field cores.

2. **Shunt-wound** (Fig. 131), in which a field winding of high resistance is connected in parallel, or as a shunt, to the external circuit, and only a portion of the current generated by the dynamo passes around the field cores through a great many turns of fine wire.

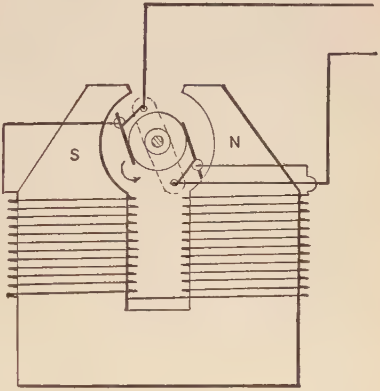

FIG. 131. — Diagram of Shunt-wound Dynamo.

3. **Compound-wound** (Fig. 132), which is a combination of the first two, so that the fields are magnetized in the same direction by both a shunt and a series winding.

If three dynamos of the same size and shape have fields wound in the three different ways, the number of ampere turns in the magnetizing coils must be the same in each. Since the series winding carries a large current, the number of times the current must pass around the magnet core to make a given number of ampere turns is comparatively small, and the winding has comparatively few turns. The shunt winding carries a comparatively small current, and this current must, therefore, pass many times around the core in order that it may have the same magnetizing effect as

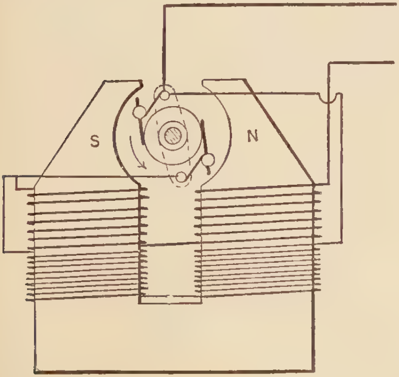

FIG. 132. — Diagram of Compound-wound Dynamo.

the large current passing a few times around the core. In the compound winding, the number of series turns and of shunt turns must be so proportioned that the number of ampere turns made up by both together shall be approximately the same as in the other cases.

**210. Characteristics of Field Windings.** — The purpose for which a dynamo is to be used almost always fixes the style of its field windings. Series-wound dynamos are ordinarily used for furnishing a current of constant strength to arc lamps which are connected in series (Fig. 133). Series windings are also used on the fields of street railway motors.

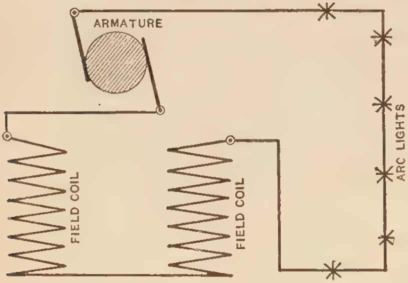

FIG. 133. — Connection of Series Arc Light Circuit with Series-wound Dynamo.

Shunt or compound wound dynamos are used for furnishing the current to incandescent lamps or electric motors which are all connected in parallel (Fig. 134), between wires which are kept at a constant difference of pressure; and shunt-wound motors are commonly used to furnish power for stationary purposes.

Compound dynamos have quite an advantage for furnishing current to be used by electric motors, that is, for *power distribution*, because they automatically keep the pressure constant through the combined action of the shunt and series field windings. The pressure supplied by shunt dynamos decreases to a certain degree as the current furnished by the armature increases, on account of the resistance of the armature, and because the magnetism set up by the current in the armature coils interferes with the field magnetism.

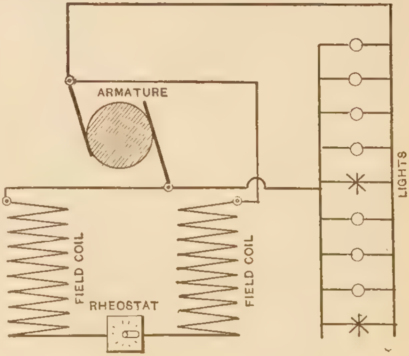

FIG. 134. — Connection of Lamps arranged in Parallel with Shunt-wound Dynamo.

The magnetizing power of a series winding, of course, increases with the current which is furnished by the machine, and the natural fall of pressure in a shunt dynamo may be entirely overcome, or even reversed, by the addition of series turns.

When shunt dynamos are used, it is necessary to regulate the strength of the field magnetism by means of a variable resistance which is connected into the field circuit as is shown in Figure 134. This resistance is often called a **Field Rheostat** or **Hand Regulator.**

**211. Materials of Construction.** — In order that the number of ampere turns required to set up the magnetism in a dynamo shall not be excessive, it is important to make the magnetic reluctance in the path of the lines of force as small as possible.[1] On account of this, the magnet frame composing the magnetic circuit of the field is made substantially of iron. In many machines good wrought iron is used because its permeability is greater than that of cast iron, but cast iron costs less per pound than wrought iron, so that some manufacturers use cast iron in the fields of their machines. In this case a greater weight of cast iron is used to make up for its lower permeability, but on account of the smaller cost of cast iron the heavier machines may not be any more expensive than the lighter ones in which wrought iron is used. Figure 135 shows a very common form of machine in which the fields are made of wrought iron, with the exception of the yoke, which is of cast iron.

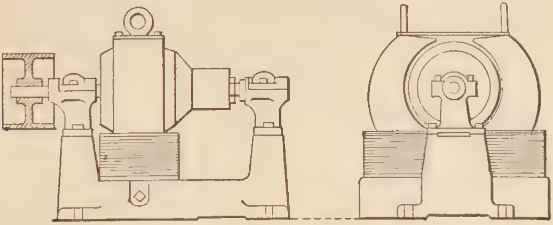

FIG. 135. — Outline Drawing of Dynamo.

In many dynamos and motors the magnet frames are made of very soft steel castings. This metal has fine magnetic qualities, and, therefore, is specially excellent for use where light weight is important. The field of the great 2000 horse power dynamo which was used to furnish current to the electric motors of the Intramural Railway at the World's Fair, and which is now furnishing current to electric street car motors, is made of steel. Figure 136 shows a street railway motor with a steel magnet frame.

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[1] Articles 130, 131, 205, and 206.

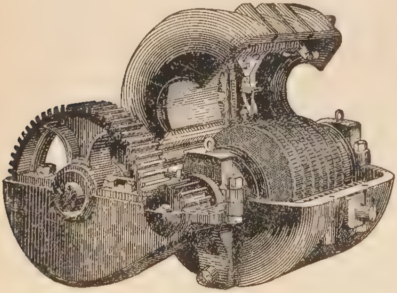

FIG. 136.—A Street Car Motor with Upper Half of Frame raised to show Armature.

Armature cores are made of disks punched from thin sheets of soft steel or wrought iron, and are held to the shaft by clamps and keys.

Not only does the material from which the frame of a dynamo is made depend to some extent upon the use for which the machine is intended, but the form of the machine is also a matter of choice which depends to a considerable extent upon the purpose for which it is to be used. For instance, the motor shown in Figure 136 is *iron-clad*, that is, the steel frame surrounds the field windings and armature. This arrangement protects the windings from danger of mechanical injury, and from the danger of being splashed by water thrown by the car wheels from puddles in the street. Water will quickly ruin the insulating qualities of the cotton thread and canvas which are largely used to insulate the wires on dynamos and motors.

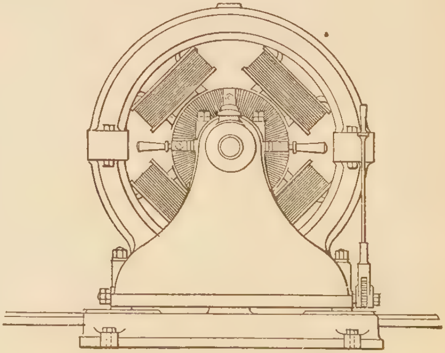

FIG. 137.—Four-pole Dynamo.

The very best copper wire, either round or rectangular in form, is used for winding armatures and fields. This wire is covered with a double or triple covering of raw cotton thread. When the wire is in place, it is varnished and baked. To keep the wires from contact with the iron, and one wire from another, mica, vulcanized paper fibre, asbestos, oiled paper, fuller board, shellacked canvas, and various other materials are used. For insulating the segments of the commutator from each other, mica is used. Great care must be exercised in thus insulating the parts of commercial dynamos, as the large amount of heat generated and the tendency of the wires to chafe against one another is apt to cause short circuits, with the resultant injury or **Burning Out** of the machines.

**212. Multipolar and Consequent Pole Dynamos.** — The dynamo shown in Figure 137 has a field with four poles, and that shown in Figure 138 has a field with twelve poles. These are called **Multipolar** to distinguish them from two-pole, or **Bipolar**, machines. Multipolar machines may have any number of pairs of poles which their dimensions will admit. The armatures for multipolar machines are wound upon the same principles as those used in bipolar machines, which have been explained.

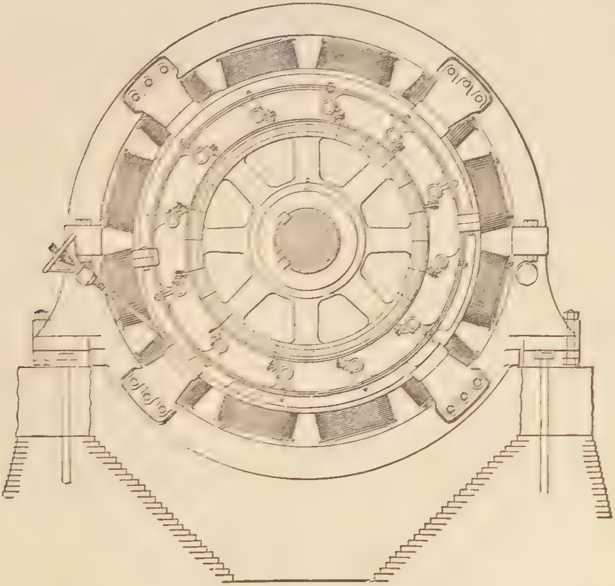

FIG. 138. — Twelve-pole Dynamo.

Figure 139 gives a diagram of a four-pole machine. The arrows indicate the magnetic circuits, of which there are four; and there are also four parallel paths in which the current may flow through the armature. The number of sets of brushes required to take the current from the commutator of a multipolar machine is commonly equal to the number of poles, but sometimes certain special connections are made in the armature, which make it possible to use only two sets of brushes.

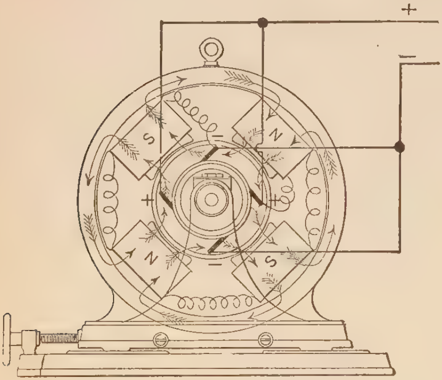

FIG. 139.—Diagram of Four-pole Dynamo.

A machine having the form shown in Figure 140 is often spoken of as a **Consequent-pole** machine, because the lines of force appear to enter the armature from the centre of the frame.

Nearly all dynamos and motors have forms which are simply variations of those shown in this article and the preceding one. Dynamo electromagnets always have an even number of poles, since magnet poles always go in pairs.

**213. Dynamo Connections.**—When a dynamo is started for the first time, it is necessary to magnetize its fields from some other machine. The iron usually holds sufficient residual magnetism[1] to thereafter start the machine into operation, and whenever started it will quickly build up its mag-

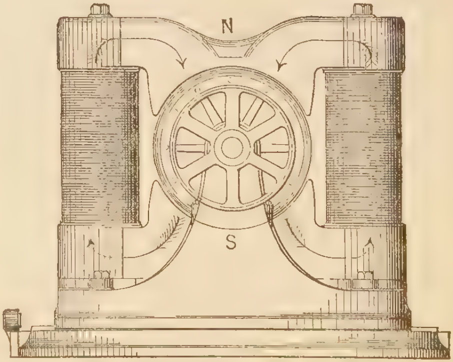

FIG. 140.—Consequent-pole Dynamo.

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[1] Article 125.

netism to full strength. In order that a dynamo may properly magnetize itself, it is necessary that the field windings be connected to the brushes, so that the current generated by the residual magnetism will pass around the fields in the proper direction. If the connections are made properly, but the direction of rotation of the armature is then reversed, the connections must also be reversed. This is illustrated in Figure 141, which shows the difference in the connections of a shunt dynamo when the direction of the armature rotation is reversed.

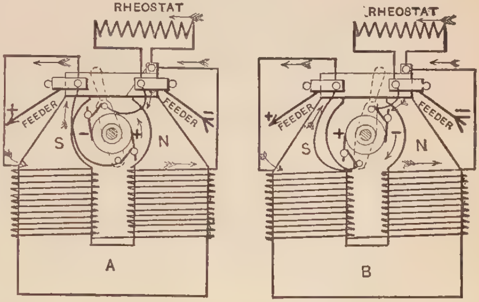

FIG. 141. — Diagram showing the Connection of Brushes and Field Windings for Both Directions of Operation.

**214. Dynamo Brushes, and their Proper Position.** — The most important detail to look after, when a direct current dynamo is in operation, is the condition and position of the brushes. Dynamo and motor brushes are sometimes made of copper, in which case a bunch of copper wires, or a number of thin copper sheets, carefully laid up together and soldered at one end, are commonly used, as are also brushes woven of fine copper or bronze wire. Copper brushes usually touch the commutator on a bevel (Fig. 142). Sometimes carbon brushes are used. These are usually blocks of copper-plated carbon, which touch the commutator either on a bevel or radially. The brushes are held against the commutator by means of spring **Brush Holders.**

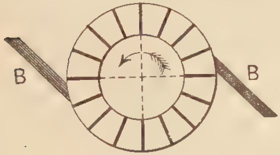

FIG. 142. — Position of Brushes *BB* on Commutator.

When in proper position, they are exactly opposite each other on a certain diameter of the commutator of a two-pole machine. With the brushes in the proper position, a good machine will usually deliver its current with little or no **Sparking**, while the machine may spark badly if the brushes are in any other position. Sparking is highly undesirable, because it tends to destroy the commutator. The position of no sparking may change with the load on the machine, in which case the brushes on a generator must be moved forward as the load increases, and the brushes on a motor must be moved backward under the same conditions. In a generator, the proper position of the brushes is slightly in advance of a plane passed between the pole tips, and, in a motor, slightly behind this plane.

**215. Features required for a Good Dynamo.** — The points required in a good generator or motor for general use are: a powerful magnetic field, which requires a small magnetic reluctance in the magnetic circuit; as little waste of power by heating as possible, which requires that the windings shall be well designed, and that a good quality of well laminated iron shall be used in the armature core; thorough insulation of the windings to prevent contact with the iron cores, and of the various turns of the windings from each other. A neat, plain finish is of advantage in an electrical machine, because it generally shows a good quality of workmanship, which is always necessary to produce satisfactory machinery. A good finish is also desirable because it quickly shows dirt and bad treatment, and thus makes evident any neglect on the part of the dynamo attendant. Dirt and dampness are two great enemies to the insulation of dynamos, and the machines must, therefore, be kept perfectly clean and dry, in order that they may operate well and last indefinitely without unnecessary repairs.

## QUESTIONS

43. On what principle does a motor work? On what principle does a dynamo work?

44. May a dynamo be used as a motor or a motor as a dynamo?

45. Does a motor generate a pressure in its windings in the same manner that a dynamo does?

46. What direction has the counter electric pressure of a motor compared with that of the pressure used to send current through its windings?

47. Why must the power applied to a dynamo armature be increased if the current generated is increased?

48. Why must the current flowing through a motor armature increase if the load on the pulley is increased?

49. Why must the speed of a motor, which has a constant field, slow up a little when the load on the pulley is increased?

50. Can a motor be made that does not develop a counter electric pressure?

51. Tell how the law of the Conservation of Energy applies to the work put into and obtained from a motor.

52. The current that flows through a motor armature is proportional to the difference of what pressures?

53. What are the causes of the power losses in a dynamo or motor?

54. What is meant by the efficiency of a dynamo?

55. What is meant by the efficiency of a motor?

56. Of what use is residual magnetism, when a dynamo is started?

57. What is series winding?

58. What is shunt winding?

59. What is compound winding?

60. Why are the windings of a series field composed of few turns of large wire?

61. Why are many turns of small wire used on a shunt field?

62. For what purposes are series-wound machines ordinarily used?

63. For what purposes are shunt and compound wound machines ordinarily used?

64. Why does the pressure of a series dynamo increase with the current?

65. Why does the pressure of a shunt dynamo decrease with the current?

66. How can a compound dynamo be made to give a constant pressure?

67. Will the pressure of a series dynamo increase with the current after the iron of the magnetic circuit has become saturated?

68. What is a field rheostat? What is it used for?

69. What kind of materials are dynamo magnetic circuits made up of?

70. Why are the conducting windings of dynamos made of copper?

71. What insulating materials are used in dynamos?

72. Why must dynamos, or motors, be kept dry?

73. What is an iron-clad machine?

74. What is a multipolar dynamo? A bipolar?

75. What is a consequent-pole machine?

76. Why must the field coil terminals be reversed, when the direction of rotation of a dynamo is reversed?

77. Would any pressure be generated by a machine, if its direction of rotation were reversed, but its field coil terminals remained the same?

78. What is the shape and material of dynamo brushes?

79. What will happen if the brushes are not placed in the right position?

80. What is the right position for dynamo brushes?

81. What effect may change of load have on the sparkless position of dynamo and motor brushes?

82. What are the important features in the construction and operation of a dynamo?

# CHAPTER XVI

## ALTERNATING CURRENTS AND ALTERNATING CURRENT MACHINERY

**216. Direct and Alternating Currents obey the Same Laws.** — A deeply rooted belief seems to have been cultivated in the minds of many, that phenomena connected with the flow of continuous electric currents and of alternating electric currents are almost entirely unrelated. This popular idea, however, is erroneous; the principles which relate to the flow of electric currents, whether direct or alternating, and which are applied to the design and construction of machines and circuits, are one and the same. It is desirable, therefore, before taking up the subject of this chapter, to give a few simple illustrations for the purpose of showing how the fundamental laws which have been treated in previous chapters apply equally to electric currents of all characters.

When Oersted, in 1820, made known his signal discovery that an electric current exerts a magnetic influence in the space around it, the foundation was begun for our knowledge of the laws of the flow of alternating currents. Within a dozen or fifteen years thereafter much knowledge of the electric current had been thrashed out experimentally by men like Ampère, Arago, Faraday, and Henry. And the last two laid the finishing stone on the foundation by searching out and making known the laws of electromagnetic induction.

The apparent flow of electric current may be likened to the flow of a fluid, and it may be either **Continuous**, **Pulsating**, or **Alternating**.

**217. Continuous Currents compared to Flow of Water.** — The first is analogous to the flow of an unbranched river through its channel, in a season of uniform flow. The water flows continuously onward without pause or hesitation. The velocity of the stream is affected by the character of the banks and the contour of the country traversed; but the onward motion of the volume of water never ceases, and the quantity of water flowing past any cross section of the channel is always the same, in a given time, though its width, depth, and velocity may change with the character of the channel. We may represent the flow in a graphic manner in this way: Suppose distances measured on the vertical from a zero or horizontal line represent the quantity of water which each minute flows past some point along the river. Then a vertical line one inch long (see Fig. 143), we will say, means that 1000 gallons of water pass the point in every minute.

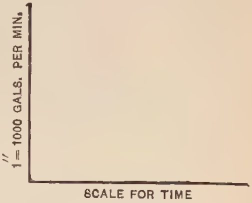

FIG. 143. — Illustration of Rectangular Coördinates.

Now suppose a number of measurements are made through twenty-four hours, and the clock times when the measurements are taken are recorded. Then we have a number of vertical lines, each one inch long, for every 1000 gallons per minute, to represent the amount of water flowing at each instant through the day and night. We can now extend our chart and divide our horizontal line of zero quantity into parts each representing one hour, as in Figure 144. And at each of the clock times set down, we may erect the vertical which has a length corresponding to the quantity of water flowing. This river is continuous in its flow, and all the verticals are, therefore, of equal height, as in Figure 145.

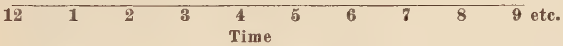

FIG. 144. — Division of Horizontal Coördinate into Parts representing Time.

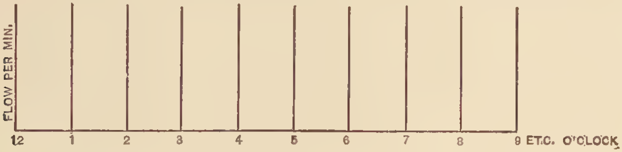

FIG. 145. — Illustration of Graphical Record of Measurements.

We may take our observations of flow as frequently as we choose, and erect the corresponding verticals at the points corresponding to the clock times of observations. Finally, by drawing a line through the tops of the verticals we have a chart which shows, by the vertical height of this line, the rate of flow at any time during the twenty-four hours (Fig. 146).

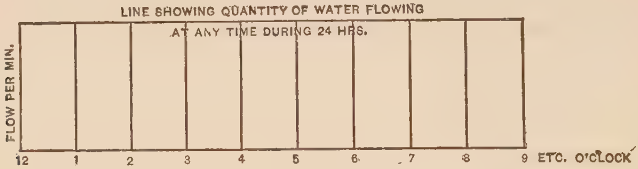

FIG. 146. — Graphical Record of Constant Current.

In the case we are considering (that of *continuous* flow) the line drawn through the ends of the verticals is a horizontal line, that is, the chart shows that the flow of the water is uniform.

**218. Pulsating Currents compared to Liquid Flow.** — A *pulsating* current may be likened to the flow of arterial blood. With each heart-beat the blood rushes forward and then slackens in velocity, and then again rushes forward as the heart beats again. Our chart, which shows the quantity of blood flowing through the artery at each instant, is in this case composed of a wavy line which never crosses the zero line, as is shown in Figure 147.

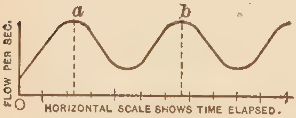

FIG. 147. — Graphical Record of Pulsating Current.

The horizontal scale now, instead of being made in hours, may be more conveniently made in seconds or fractions of a second, since the blood pulsations come many times per minute; and the vertical scale may be made to represent a flow in fractions of a fluid ounce per second instead of gallons per minute, because of the limited amount of blood that flows in an artery. The vertical height of the wavy line in the chart (above the horizontal scale line) still shows the amount of blood flowing at each instant, corresponding to the times read on the horizontal scale. The **Frequency** of the heart-beats is the number of pulsations made per minute, which is not far from 70 in the average human adult, and the duration, or **Period**, of the pulsations is, therefore, not far from

$\frac{1}{70}$ of a minute. The period is represented on the chart by the time that has elapsed between two like points, as the two points of greatest flow, *a* and *b*.

**219. Alternating Currents compared to Flow in Tideway.** — Finally, the *alternating* current may be likened to the flow of water in a narrow tideway. As the tide rises, the water rushes up the channel until near high tide, when the flow gradually ceases, turns, and then with increasing flow the water rushes down the channel until near low tide, when its outward flow gradually ceases, turns, and with increasing flow the water begins to rush up the channel again. The action is repeated again and again as the days pass by. The *period* of the complete action, or **Cycle**, is little over twelve hours, and the *frequency* is, therefore, nearly two periods per day. We can represent this *alternating flow*, or *current*, also by a chart, as shown in Figure 148.

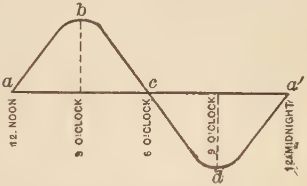

FIG. 148. — Graphical Record of One Cycle of Alternating Current of Tidal Flow.

Assuming the period to be exactly twelve hours (which is near enough for the analogy), and taking a day in which low tide occurs at 12 o'clock, noon, then, at this time (12 o'clock, noon), no flow is occurring; a little later the flow is up the channel as the tide rises, and the rate of flow increases for a time. This portion of the tidal period is represented by the portion of the curve between *a* and *b* in Figure 148. It is to be borne in mind that the vertical height of the curve shows the amount of water flowing per minute at the instant considered (not the height of the water). The flow continues up the channel for a further length of time, but at a decreasing rate, until high tide is reached at 6 P.M. Then, for an instant, there is no flow of the water. In representing this, our curve (dropping down from *b*) crosses the line of zero flow at the point marked *c*, which corresponds to the instant of no flow at the time of high tide.

Half a tidal period has now been completed; the tide has reached its flood, and begins to fall, and the flow, therefore, reverses and runs outwards. Since the flow inward or up the channel is shown on the chart by a vertical distance above the line of zero flow, it is natural to represent the outward flow by a vertical distance below the line. After the turn of the tide, the amount of flow increases for a time up to the maximum, and then decreases as the low tide is approached. This is represented by the curve from *c* through *d* to *a'*. At the latter point low tide has been reached, and an entire cycle of the tide has been completed, and is represented on the chart. The chart might be continued indefinitely, representing the cycles of successive periods if desired, as in Figure 149.

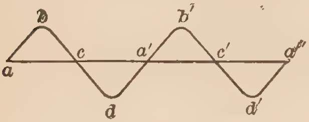

FIG. 149. — Graphical Record of Two Cycles of Alternating Current.

**220. Phase of Flow.** — It is well known that the character of the tidal flow is greatly affected by the character of the channel. For instance, in a narrow, crooked channel the phase of the flow is retarded as one proceeds along its length, through the buffeting action of the banks; and the times of high and low tides, when the flow in the channel is zero, may not correspond with the times of similar tidal phases in some other channel or in the open sea. In this case we may say that the tide in one channel **Differs in Phase** from that in the other or that in the sea; and a chart may be drawn to represent the respective cycles of sea and channel tides at certain selected points, as in Figure 150. In this figure the tidal cycle in the channel is shown to be **Retarded,** *or behind the tidal cycle of the sea.*

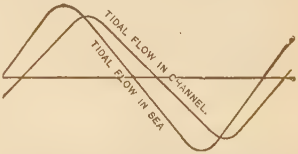

FIG. 150. — Graphical Record of Two Alternating Currents which differ in Phase.

Alternating currents of electricity, flowing in branch circuits, may be at different phases, and they may be represented on a chart entirely similar to that of Figure 150. The currents are said to be **Out of Phase**, and may be said to be in advance of or behind each other, depending upon which is looked upon as the datum for comparison, — exactly, for instance, as we may with equal propriety and the same meaning say either that the channel tide is behind the tide of the open sea, or that the tide of the open sea is in advance of the channel tide.

**221. Summing Up.** — To recapitulate, the electric current may be **Continuous**, **Pulsating**, or **Alternating**. The first is likened to a continuous flow of a river; the second, to the pulsating flow of arterial blood; and the third, to the alternating flow of water in a tideway. Continuous and pulsating currents, that is, currents which flow continuously in one direction, are called **Direct Currents.**

**222. Electric Current Flow compared to the Flow of Water from Pumps.** — We may give another set of analogies so as to emphasize the relations still more decidedly.

1. A *continuous current* is like the uniform current of water set in motion by means of a centrifugal pump operated at a constant speed (Fig. 151).

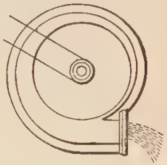

FIG. 151. — Centrifugal Pump, setting up Continuous Current of Water.

2. A *pulsating current* is like the current of water set in motion by a piston pump. As the piston moves forward in the water cylinder the water therein is forced to flow through the delivery pipe. When the piston reaches the end of its stroke the flow slackens or ceases, and, as the piston returns on the stroke, the flow again proceeds as before through the delivery pipe, and slackens as the piston reaches its initial position (Fig. 152). This is repeated as the stroke is repeated, and the action causes a succession of impulses to the water, with intervening pauses or slackening of the current.

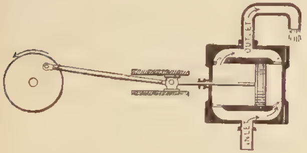

FIG. 152.— Piston Pump, setting up Pulsating Current of Water.

3. An *alternating current* is like the current of water which would be set up in case the delivery and suction pipes of the piston pump were connected directly together, and the valves removed. Now, as the piston moves back and forth, the water flows unceasingly back and forth, alternately from one end of the cylinder to the other, as long as the pump is operated (Fig. 153).

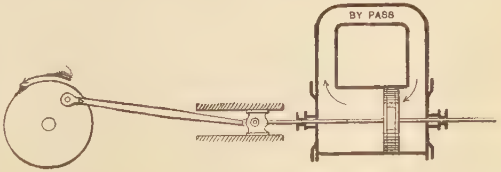

FIG. 153. — Piston Pump with By-pass, setting up Alternating Current of Water.

Figure 153 shows clearly that a complete cycle of the alternating current is produced with each revolution of the pump-driving shaft, that is, with each 360 degrees of angular motion of the shaft. We may, therefore, for the sake of convenience, divide the horizontal zero line or axis in our charts into 360 parts for each *period* of the flow, and call the parts *degrees* instead of fractions of time. This is illustrated in Figure 154, which shows two alternating currents of different phases. We may speak of these as having 30 degrees difference of phase, or they are 30 degrees apart, since they cross the horizontal axis at points which are 30 divisions or degrees apart.

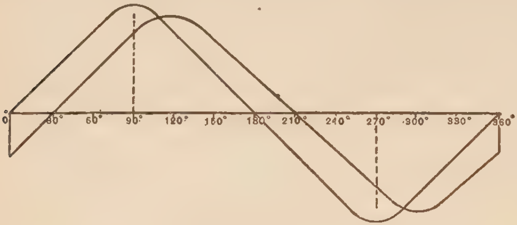

FIG. 154.—Two Alternating Currents with 30 Degrees Difference of Phase.

**223. Forms of Current and Pressure Curves.** — The alternating curves which are shown in the preceding figures are all smooth curves, but actual waves of alternating electric currents and pressures are usually more or less irregular in outline, and sometimes they are very irregular; but successive loops are ordinarily similar. Two alternating current curves, the outlines of which were determined by experimental means, are shown in Figures 155 and 156.

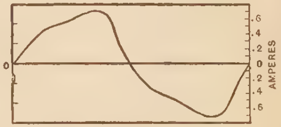

FIG. 155.—Actual Curve of Alternating Electric Current.

It is also a fact that alternating current curves do not have the same shapes, whenever any iron is magnetized by the currents, which is usually the case, as the waves of pressure which are applied to the circuits to produce the currents. The curve in Figure 155 was set up by a smooth pressure wave with a form quite like a sine curve, while the curve in Figure 156 is a curve of current which

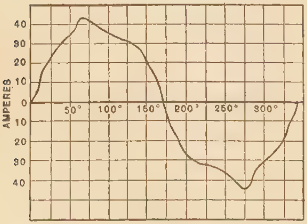

FIG. 156.—Actual Curve of Alternating Current drawn by Student in Electrical Laboratory at University of Wisconsin.

was set up by a quite flat-topped, steep-sided pressure wave. Changing the iron or other conditions of the circuit would produce changes in these current curves, though the pressure curves remained unchanged.

**224. Electromagnetic Inertia or Self-induction.** — If a heavy block is suspended so that it is perfectly free to move, and then is struck a sharp blow, for an instant it offers a force which opposes the force of the blow almost as though the block were rigidly fastened. This opposing force is well known to be caused by the **Inertia** of the block. Inertia sets up a force which tends to violently oppose any sudden change in the motion of a body, and when the suspended block is started swinging it may strike a considerable blow upon its own account when met by an obstacle.

When an electromotive force is introduced into an electric circuit, the circuit, by a kind of *electromagnetic inertia*, opposes the immediate flow of the current (very much as the inertia of the suspended block opposes the force of a blow before the block moves), and the rise of the current in the circuit is retarded. If the circuit is severed or broken while current is flowing, the electromagnetic inertia makes an effort to uphold the current (as the swinging block is difficult to stop), and an electric spark appears as its evidence in the gap between the severed ends of the wire.

Joseph Henry originally discovered the cause of this retarding effect about 1832, and Faraday (whose name is almost a household word on account of his discoveries in natural philosophy, and especially in electricity and magnetism) was well acquainted with it as early as 1835, and describes it in his "Experimental Researches." He says: "Returning to the phenomena in question, the first thought that arises in the mind is that the electricity circulates with something like *momentum* or *inertia* in the wire, and that thus a long wire produces effects, at the instant the current is stopped, which a short wire cannot produce. Such an explanation is, however, at once set aside by the fact that the same length of wire produces the effects in very different degrees, according as it is simply extended, or made into a helix, or forms the circuit of an electromagnet." He then shows that the apparent inertia is due to the magnetic effect of the current. For instance, he says, "Further investigation led me to perceive the inaccuracy of my first notions, and ended in identifying these effects with the phenomena of induction which I had been fortunate enough to develop in the first series of these experimental researches."

Faraday further speaks of this as a *retardation* of the electric current in the circuit, and ascribes the effect to the "induction of the current itself," or "*self-induction*" of the circuit.[1] The phenomena of electromagnetic induction were studied about 1850 (fifteen years after Faraday's experiments) by Sir William Thomson (now Lord Kelvin), Helmholtz, and other scientists, who brought to their aid the powerful resources of mathematics, and their work was canvassed and discussed by Maxwell in his book on electricity and magnetism, who showed that the effect of **Self-induction** is truly the result of **Electromagnetic Momentum**, or **Inertia.**

**225. Lag of an Alternating Current.** — The retardation of the current by electromagnetic inertia was shown by Faraday to occur *when the current is changing in value*, and it, therefore, exercises a marked influence on the *ever changing alternating current.* Faraday showed that the value of the changing current was retarded, or **Lagged**, behind the value which it might be expected to attain, and which a uniform current under the same conditions would attain. We therefore know that an alternating current will lag behind the phase of the alternating electromotive force which causes it to flow, if there is self-induction in the circuit. The amount of the lag depends upon the electromagnetic character of the circuit. Thus, a straight wire causes less **Retardation**, or **Lag**, than the same wire wound in a helix, because the helix increases the magnetic effect. Inserting an iron core in the helix may increase the retardation enormously, since the presence of the iron again increases the magnetic effect. Faraday said: "If an electromagnet be employed, the effect will be still more highly exalted," as compared with the effect of the plain coil or helix of wire.

Faraday's experiments were mostly carried on with varying or pulsating currents, but later investigators took hold of alternating currents, and much attention was given to the laws of flow of such currents at the time alternating current dynamos became known.

**226. Ohm's Law Modified for General Application.** — We have studied in previous chapters the well-known ratio generally called Ohm's Law, in which it is asserted that a continuous current is equal to the electrical pressure upon a circuit divided by the electrical resistance of that circuit. This so-called law is nothing more than a special statement of a condition which may be recognized as universally applicable to the phenomena of nature. The general statement may be put thus: The result of an effort is equal to that effort divided by the opposing resistance. Thus, for example, if we stretch an elastic material, the amount of stretch depends upon the ratio of the pull to the elastic resistance of the material; if we try to push a heavy block along the floor, the velocity of the block depends upon the ratio of the force exerted to the frictional resistance opposing the motion; and so we could go on indefinitely illustrating the general applicability in nature of this statement that any *result* is dependent upon the ratio: *effort* divided by *resistance*.

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[1] Article 142.

We then have for the flow of continuous currents the rule that current flowing (*result*) is equal to pressure (*effort*) divided by the opposition to the current flow (*resistance*); but in the case of continuous currents there is no opposition to the flow of the current except electrical resistance (that is, the resistance which is determined by the nature, temperature, and dimensions of the conductor), whence we have Ohm's Law for the flow of continuous currents.

The fundamental law of the flow of alternating currents follows directly from what has gone before. The alternating current flowing in a circuit is equal to the pressure divided by the opposition to the flow of the current. In this case the opposition is made up of two parts, one the electrical resistance spoken of above, and the other the opposition due to electromagnetic inertia.

We have already learned how an alternating current may be produced in an armature having a single coil of wire which is revolved between two pole pieces.[1] The ordinary alternating current dynamo or **Alternator** is designed on this principle, but is usually constructed with a number of coils on the armature and with an equal number of poles in the field magnets. In general construction an alternator is similar to a continuous current dynamo, but before we enter into a discussion of the detailed arrangements it is well to consider certain facts in regard to the alternating current.

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[1] Article 196.

## QUESTIONS

1. Do the same laws apply to the flow of all forms of electric currents?

2. What great discovery did Oersted make?

3. What three classes may electric currents be divided into?

4. Compare the flow of a continuous current to the flow of a river.

5. Compare a pulsating current to the flow of blood in an artery.

6. Compare alternating current to flow of water in a tideway.

7. What are the "frequency" and "period" of a tidal current?

8. How can the "phase" of the flow of water in a tideway differ in different places?

9. Describe pumps that will give continuous, pulsating, and alternating currents.

10. What is meant by the statement that two alternating currents differ in phase by 45 degrees?

11. Are alternating current and pressure curves necessarily similar or regular in form?

12. Illustrate the effect of mechanical inertia.

13. Compare the inertia of a block to a similar property of electric circuits.

14. Give a brief historical account of the discoveries concerning self-induction.

15. Why does self-induction have an especially important effect upon alternating currents?

16. If an alternating current is sent through a self-inductive circuit, will its value at any instant be the same as though the circuit were non-inductive?

17. What would be the effect upon the self-induction of a coil if an iron core were placed within it?

18. Give a number of illustrations of the ratio expressed in Ohm's Law.

19. What is an alternator?

**227. Chemical Effect of an Alternating Current.** — If a pulsating current which varies in value like that represented in Figure 157 is passed through a voltameter,[1] the amount of metal, copper for instance, which is carried by the current from the anode to the cathode is proportional to the average value of the current. In other words, the *electrolytic effect of a pulsating current is dependent upon the average value of the current.* The electrolytic effect of the pulsating current represented by Figure 157 is the same as that of a uniform current the magnitude of which is represented by the height of the line *FG* above the line *AE*.

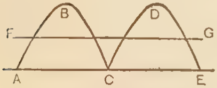

FIG. 157. — Pulsating Current.

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[1] Article 157.

If the current from a single coil armature is not commutated, but is led into the external circuit by means of collecting rings,[1] as is done in telephone magnetos, the second loop of the curve representing the current falls below the line *AE*, because the current flows alternately in one direction and then in the other. This is shown in Figure 158, where the perpendicular distances from the line *OX* to the wavy line are proportional to the strength of the current in the circuit at each instant. During the times represented by the distances *AC*, etc., in which the loops are above the line *OX*, the current is supposed to flow in one direction, and during the intervening times, *CE*, etc., in which the loops are below the line *OX*, the current is supposed to flow in the other direction.

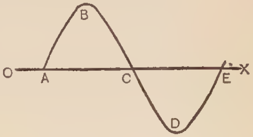

FIG. 158. — One Cycle of Alternating Current.

*Such an alternating current can have no electrolytic effect in an electrolytic cell like the copper voltameter described in article 157*, since the electric current which flows in one direction for one instant flows in the opposite direction for the next instant, and consequently the voltameter plates are alternately anode and cathode.

**228. Heating Effect of an Alternating Current; Instantaneous Squares.** — A different relation exists in regard to the heating effects of pulsating and alternating currents. It is to be remembered that the heating produced by a continuous current when it flows through a circuit is equal to the current squared multiplied by the resistance of the circuit.[2] *The heating produced by a pulsating current is equal at every instant to the value of the current at that instant squared and multiplied by the resistance of the circuit.*

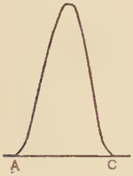

FIG. 159. — Curve representing Squares of the Ordinates of one Loop of Pulsating Current.

A curve may be drawn, as shown in Figure 159, the height of which at each point is equal to the square of the corresponding height of the curve representing the current. The height of this curve of squares at each point is proportional to the power expended in heating the circuit at the corresponding instant. *The same total power would be expended on the circuit by a continuous current whose square is equal to the average height of the curve of squares.*

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[1] Article 196.

[2] Article 112.

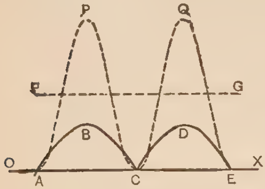

FIG. 160. — Curve of Squares for Two Successive Loops of Pulsating Current.

In Figure 160, the line *APCQE* represents the curve of squares like that already shown in Figure 159 extended to two loops, which correspond with the two loops of pulsating current *ABCDE*, and the height of the line *FG* above *OX* represents the square of the continuous current which causes the same heating in the circuit as the pulsating current. The height of the line *FG* is greater than the square of the average value of the pulsating current, and consequently *the heating effect of a pulsating current is greater than that of a continuous current equal to its average value.*

The reason for the latter fact may be easily seen. The squares of numbers increase in magnitude much more rapidly than do the numbers themselves. For instance, 6 is twice 3, but the square of 6, or 36, is four times the square of 3, which is 9. On account of this, *the average of the squares of different positive numbers is always greater than the square of the average of the numbers.* For instance, the average of 2, 5, and 8 is 15 divided by 3, or 5, and its square is 25. The squares of these numbers are respectively 4, 25, and 64, which gives an average of 93 divided by 3, or 31. Now, if we square the values of the pulsating current at each instant, we have the squares of a large number of values which range from zero to a maximum, and the average of these squares is greater than the square of the average of the original values.

*Since the heating effect of a current is entirely independent of its direction, an alternating current, such as one of those illustrated in Figures 155, 156, or 158, expends exactly the same power in heating a circuit of given resistance as it would if commutated into a pulsating current.*

**229. Product of Current and Pressure.** — When there is no self-induction or outside disturbing factor in a circuit, the power expended in the circuit is always equal to $C \times E$ (current times electric pressure). Here, again, when the pressure and resulting current are pulsating or alternating, we have a series of products of values, the average of which is greater than the product of the respective averages of the current and pressure.

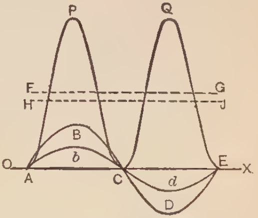

FIG. 161. — Alternating Current, Pressure, and Power Loops.

The line *ABCDE*, in Figure 161, represents the electric pressure applied in a circuit, and *AbCdE* the resulting current. At each instant the power expended in sending the current through the circuit is equal to the product of the corresponding heights of these two curves. The height of the curve *APCQE* at each point is equal to the product of the corresponding heights of the current and pressure curves. Curve *APCQE* may, therefore, be called a power curve. Both its loops are placed above the line *OX* because they both represent power expended in the circuit.

The average power expended in the circuit is represented by the height of the line *FG*, which cuts off the tops of the loops so that they will exactly fill up the intervening valleys. The height of the line *HJ* represents the product of the average current by the average pressure, which is seen to be less than the average power represented by the height of the line *FG*.

**230. Effective Current and Pressure.** — When we measure the value of an alternating current we desire to find the value which, when squared and multiplied into the resistance of a circuit, will give the heating effect of the current. This is called the **Effective** *value of the current* or the **Effective Current**, and it is greater than the average value of the current, as we have already seen.

In measuring an alternating electric pressure or electromotive force we likewise desire to find the value which, when multiplied into the effective current which it causes to flow through a circuit without self-induction, will give the power expended in the circuit. This is called the **Effective Pressure** or **Effective Electromotive Force**, and is larger than the average pressure.

From the explanation given above, it is seen that the effective value of an alternating current or an alternating electric pressure *is equal to the square root of the average of all the squares of the instantaneous* *values of the current or pressure during the time represented by one loop in the figures.* The effective value is, therefore, often spoken of as the "*square root of the mean* (*average*) *square.*" The power in a circuit without self-induction is equal to the product of the effective current and pressure.

**231. Alternating Current Measuring Instruments.** — Since the indications of an electrodynamometer or of a hot wire electrical measuring instrument are proportional to the square of the current flowing through the instrument,[1] such instruments are excellently adapted to measuring alternating currents. The number of alternations made in each minute by the alternating currents which are ordinarily used is so great that the movable coil of an electrodynamometer acts exactly as though it were pulled around by a continuous force *proportional to the average of the squares of the instantaneous values of the current.* The square root of the

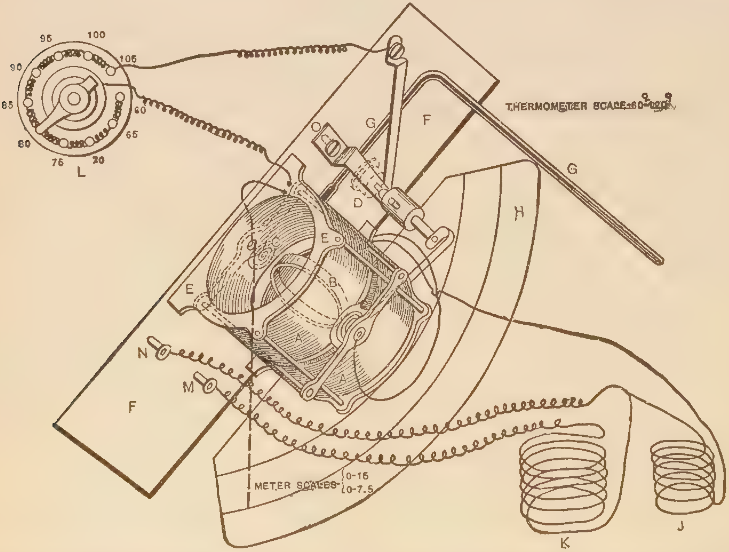

FIG. 162. — Perspective View of Interior of Weston Alternating Current Voltmeter from below.

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[1] Articles 176 and 178.

indication of the instrument is, therefore, proportional to the effective value of the alternating current flowing through its coils. One form of electrodynamometer which is commonly used for measuring alternating currents is shown in Figure 99. The mechanism of an alternating current voltmeter made upon the same principle is shown in Figure 162. It

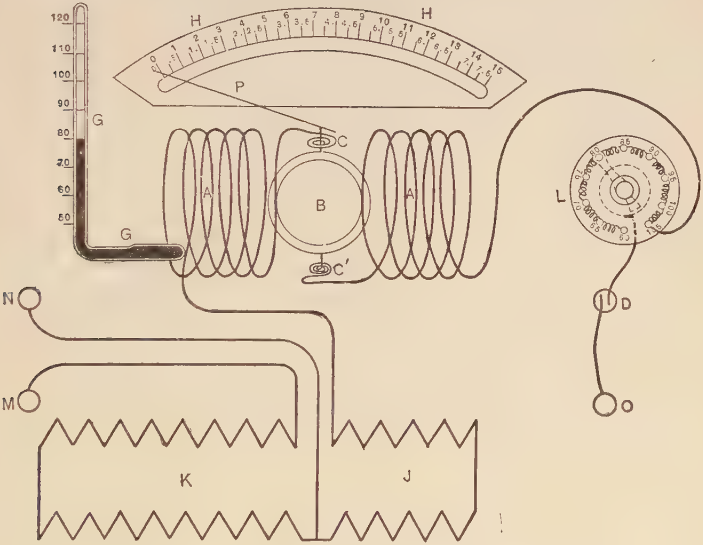

FIG. 162*a*. — Diagram of Weston Alternating Current Voltmeter.

is evident, as these instruments measure continuous currents or pressures, or effective alternating currents or pressures, on the same scale, that we may consider the alternating values as equivalent to continuous currents or pressures that have the same heating effect in a circuit.

The construction of the Weston alternating current voltmeter may be understood by following the figures, which are lettered alike. The instrument is constructed on the principle of the electrodynamometer. *B* is the movable coil, and *AA* is the stationary or fixed coil. *M*, *N*, *O* are binding posts. *J*, *K* are extra resistances. *L* is a special variable resistance used to correct the readings for variations of temperature. *D* is a push button switch, and *C*, *C′* are springs through which the current enters and leaves the movable coil. *P* is the needle or pointer, *H* is the scale which is engraved with two sets of figures, and $G$ is a thermometer with its bulb near the coils of the instrument and its stem in view near the scale of the instrument. The instrument is usually boxed up so that only the scale $H$, $H$ over which the pointer moves, the dial of $L$, and the stem of the thermometer are visible.

When the instrument is in service, the voltmeter is connected to the circuit by means of the binding post $O$, and either the binding post $M$ or the binding post $N$. When the button $D$ is depressed, current flows through the fixed and movable coils and through the resistance $J + K$ or $J$ alone (depending upon which binding post — $M$ or $N$ — is used), and the pointer is caused to move over the scale by the movement of the movable coil which is caused by the electromagnetic attractions between the current in its windings and the current in the windings of the fixed coil.

A pointer on the dial $L$ is set at a mark which corresponds to the temperature indicated by the thermometer, and more or less of the resistance coils connected to the dial are thus included in the voltmeter circuit. In this way the resistance of the voltmeter, measured from binding post to binding post, may be kept uniform, regardless of the temperature of the instrument, and the readings are thus corrected for variations of temperature. The resistance of the windings $AA$ and $B$, added to the resistance $J$, is just equal to one-half of the resistance of the same windings plus the resistance of $J + K$. Consequently only half as much electrical pressure between the instrument terminals is required to cause a given movement of the needle when the binding posts $O$ and $N$ are used, as when the binding posts $O$ and $M$ are used. The scale which reads up to 7.5 volts, in the instrument illustrated, is therefore used in connection with binding posts $O$ and $N$, and the scale which reads up to 15 volts with the binding posts $O$ and $M$. The movement of the coil and pointer is opposed by the springs $CC'$ [1] and the scale is engraved so that the instrument is direct reading.[2]

Since hot wire instruments also average up the squares of the instantaneous values of the current, they are now used to a considerable extent for measuring alternating currents. They are made into voltmeters and shunted amperemeters[3] upon the same principle as the Cardew voltmeter[4] which has long been used as an alternating current instrument. Electrostatic voltmeters[5] also give indications, the square roots of which are proportional to effective alternating pressures, when the needle is electrically connected to one pair of quadrants, as is usually done. The scales of all these instruments may be so graduated as to be direct reading. Magnetic vane instruments which are described in Article 180 also are used satisfactorily in alternating current measurements.

Alternating current wattmeters are made upon the plan of an electrodynamometer with a coil of low resistance for connecting in series with

[1] Articles 174, 175. [2] Articles 179, 182. [3] Article 181. [4] Article 182. [5] Article 183.

the circuit, and a coil of high resistance for connecting across the terminals. These instruments are in every respect the same as wattmeters intended for use in direct current circuits described in Article 187.

**232. Frequency and Period of an Alternating Current.** — An alternating current is said to make as many **Alternations per Minute** as it makes changes in direction in each minute. Instead of speaking of the number of alternations per minute of an alternating current it is quite common and more scientific to speak of its **Frequency**,[1] that is, *the number of double alternations made per second.*

The early alternating current dynamos which were generally used in this country furnished currents making from 15,000 to 16,500 alternations per minute, or frequencies of from 125 to 137.5 periods per second; but frequencies only half as great, and even less, have come into use during later years, and the commonest frequency used in this country is now 60 periods per second or 7200 alternations per minute. The great power plant at Niagara Falls uses a frequency of 25 periods per second.

The number of alternations per minute is equal to 2 × 60, or 120 times the frequency, since 60 is the number of seconds in a minute. The fraction of a second during which an alternating current makes two loops is called its **Period**.[2]

*Example A.* If an alternating current has a frequency of 100 periods per second, how many alternations does it make per minute? *Ans.* 12,000.

*Example B.* What is the frequency of an alternating current making 6000 alternations per minute? *Ans.* 50.

*Example C.* What are the periods in examples A and B? *Ans.* $\frac{1}{100}$ and $\frac{1}{50}$ of a second.

**233. Effect of Self-induction on the Flow of Alternating Currents.** — The very important effects of electromagnetic inertia on the flow of alternating currents[3] makes them appear to be more complex than continuous currents. The point is so important that it must be given very careful attention.

When a *continuous current* is passed through an incandescent lamp, the amount of power expended by the passage of the electric current through the lamp filament, which is converted into heat and light, is equal to $C \times E$. In the same way, when an *alternating current* is passed through an incandescent lamp, the amount of power which is expended in the lamp filament, and converted into light and heat, is also equal to $C \times E$, where $C$ and $E$ are the effective values of the current and pressure measured by the proper alternating current instruments which were explained in Article 231. We therefore see that an incandescent lamp which is intended to give sixteen candle-power at a pressure of, say 110 volts, will be equally efficient when it is connected to a constant pressure circuit which furnishes it continuous current at a uniform pressure of 110 volts, or when it is connected to a circuit which furnishes it alternating current at an effective pressure of 110 volts. If the current flowing through the lamp when it is connected to the continuous current circuit is measured by an accurate amperemeter of any kind, and a measurement also is made when the lamp is connected to the alternating current circuit by an accurate electrodynamometer, exactly the same amount of current will be found to flow through the lamp in the two cases.

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[1] Article 219.

[2] Article 219.

[3] Articles 224, 225, 226.

Now, suppose we take 200 feet of No. 7 B. & S. gauge insulated copper wire. Its resistance is almost exactly one-tenth of an ohm at ordinary temperatures, and it, therefore, requires only one-tenth of a volt to send one ampere of continuous current through it. This is true whether the wire is stretched out straight, wound in a simple coil, or wound around an iron core, since the resistance of the wire at a given temperature depends only upon its length, cross section, and material,[1] and none of these are altered by coiling or winding up the wire.

To send one ampere of alternating current of, say, a frequency of 125 periods per second (15,000 alternations per minute) through this wire when it is stretched straight out requires a tenth of a volt effective pressure, or the same as in the case of a continuous current. *The straight wire*, therefore, *acts in practically the same way toward continuous and alternating currents*, exactly as does the incandescent lamp filament, which, indeed, is nothing more than a bent wire made of carbon.

Now, *if the wire is coiled up, a greater pressure than one-tenth of a volt will be required to send one ampere through the wire, while if it is wound on a big laminated iron core there may be as much as 100 volts, or even more, required to send an ampere through the wire.*

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[1] Article 95.

We know that *the resistance of the wire is not changed by coiling it up or by winding it around an iron core,* so that the actual resistance is one-tenth of an ohm all the time. This is proved by the fact that coiling the wire and winding it around an iron core does not change the amount of pressure required to send one ampere of continuous current through it. It also may readily be proved by measuring the resistance of the wire by a Wheatstone bridge when the wire is stretched straight out and when it is wound on an iron core.

The action of the alternating current as thus seen might lead us to suppose that the flow of alternating currents does not follow Ohm's Law.[1] The flow of alternating currents does follow a law like Ohm's, however, and the peculiar action described is explained in the following articles.

**234. Effect of Self-induction is caused by the Magnetic Field created by the Current.** — In Articles 142 and 224 it is described how either an increase or a decrease of current in a coil is retarded by the *magnetic effect of the different turns of the coil tending to stop any change in the current.* This effect is magnified to a large degree when the coil is wound on an iron core, since the iron largely increases the magnetic effect of the turns and so increases the self-induction of the coil; while a wire stretched out straight or bent in a hairpin, like an incandescent lamp filament, has very little self-induction.

When a battery is connected so as to send a current through a straight wire the current rises to its full value, according to Ohm's Law, almost instantly. When the same wire is coiled up and connected to the battery, the current does not rise to its full value instantly on account of the retarding effect of self-induction, but the delay is only a very small fraction of a second. Now, when the wire is wound on an iron core and then connected to the battery, the effect of self-induction is so great that it takes quite an appreciable portion of a second for the current to rise to its full steady value. *The final steady value reached by the current is not changed by the self-induction, but is just the same in each case if the pressure is uniform, because the self-induction can have an effect only while the current is changing in value.*

As explained in Article 142, when a current is rising in a coil it sets up lines of force, which in turn set up a counter-electromotive force which dams back the current; but when the current is falling, the disappearing lines of force set up a pressure in accord with the direction of the current which tends to keep the current flowing.

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[1] Article 92.

**235. Current Lag.**[1]— *An alternating current changes all the time,* so that it never has a steady value, and *the effect of self-induction is therefore felt by it all the time.* While the current is rising, self-induction tends to hold it back or keep it from rising, and when the current is falling, self-induction still tends to keep it from changing. The result is that *in a circuit having self-induction an alternating current is always retarded a certain amount behind the alternating pressure which sets it up.* The current is said to have a **Lag.** This same retardation causes the *maximum value of the current to be smaller than it would be were there no effect of self-induction.*

**236. Impedance.** — We, therefore, see that, where an alternating current flows through a circuit which has such a form that its self-induction is appreciable, the alternations made by the current come a small fraction of time later than those made by the electric pressure, and the value of the current is smaller than if no self-induction were present. The effect is exactly as though the current loops of Figure 161 were not placed directly under the pressure loops, but were pushed a certain small amount back of the position of the pressure loops. The curves are so drawn in Figure 163, which is similar to Figures 150 and 154.

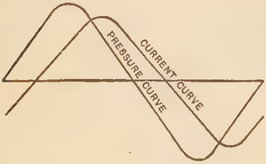

FIG. 163. — Lagging Current.

The effect of self-induction in decreasing the amount of alternating current which flows in a circuit depends upon the magnetic effect which the different parts of the circuit have on each other, and also upon the frequency of the current. The same result is brought about as would be given by increasing the resistance of the circuit a certain amount. It is therefore usual to speak of the **Apparent Resistance**, or **Impedance**, of a circuit through which an alternating current flows.

*The effective current in an alternating circuit is equal to the effective electrical pressure applied to the circuit divided by the* **Impedance** *of the*

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[1] Article 225.

*circuit.* This may be called the Ohm's Law of the alternating current circuit.

*The* **Impedance** *is a combination of the true resistance of the wire composing the circuit with the effect due to self-induction.* The true resistance of the wire *depends only upon its length, cross section, and material,* while the effect of self-induction *depends upon the magnetic effect of the different parts of the circuit, and upon the frequency of the current.*

When a continuous current flows through a circuit, the true resistance of the circuit, as measured by a Wheatstone bridge, only need be considered, but when an alternating current flows through the same circuit, the impedance comes into account.

The remarkable results which are brought about in alternating current circuits, on account of the current hanging back or **Lagging** behind the electrical pressure will now be considered. Before entering upon this subject the student should study the preceding descriptions until he gets a true idea of the lagging of the loops of an alternating current behind the pressure which sets up the current, and the cause of this lagging.

## QUESTIONS

20. Why is the electrolytic effect of a pulsating current dependent on its mean value?

21. Why does an alternating current ordinarily produce no electrolytic effect in a water voltameter?

22. Why is the heating effect of a pulsating or of an alternating current greater than that of a continuous current of the same average value?

23. Is the heat produced by an electric current when flowing through a circuit affected by the direction of its flow?

24. Why is the actual power in a non-inductive alternating circuit greater than would be indicated by multiplying together the average values of current and pressure?

25. What is meant by the phrase "effective current"?

26. What is meant by the phrase "effective pressure"?

27. Why are effective values of currents and pressures used instead of average values?

28. What is the power in a non-inductive circuit equal to, in terms of effective current and pressure?

29. Why are instruments based on the principle of the electrodynamometer, or on the hot-wire principle, usually used in measuring alternating currents?

30. Why are instruments based on the principles named in Question 29, or on the electrostatic principle, usually used in measuring alternating voltage?

31. What would be the effect of putting an amperemeter having a permanent magnet in series with an alternating current circuit? Why would it not give a reading?

32. Can soft iron core instruments be made so that they can be used on alternating current circuits? Explain the action.

33. Describe a wattmeter that may be used on alternating current circuits.

34. What is meant by the frequency of an alternating current?

35. What is meant by the period of an alternating current?

36. What frequencies are commonly used?

37. Will essentially the same current flow through a straight wire under a given pressure whether it be continuous or alternating?

38. Suppose the wire of 37 is coiled up?

39. Suppose an iron core is inserted in the coil of 38?

40. What causes the effects of self-induction?

41. Why is a self-inductive pressure set up in a circuit only when the current is changing?

42. Why is it that when a steady pressure is impressed upon a self-inductive circuit the self-induced pressure acts against the impressed pressure while the current is rising?

43. Why is it that the induced pressure is in the same direction as the impressed pressure when the current is falling?

44. Explain why an alternating current lags in a self-inductive circuit.

45. Is the apparent resistance which an inductive circuit offers to the flow of an alternating current greater than the resistance due to the form and material of the wire?

46. What is impedance?

47. Give the generalized form of Ohm's Law as it applies to the flow of alternating currents.

**237. Power in a Self-inductive Alternating Circuit.** — In Article 229 it was explained that the power in an alternating circuit is equal at any instant to the product of the instantaneous pressure and current, and that its average value is the average of these products. Where the curves of pressure and current are in the same phase, the power loops are as shown in Figure 161, but if the current lags on account of self-induction, as in Figure 163, the power loops are altered in position and become as illustrated in Figure 164.

It is seen in this figure that there are large positive loops and small negative loops. The negative loops are located between the points *ab* and *cd*, where the current and pressure curves are on opposite sides of the horizontal line. This means that during part of each half period work is being absorbed by the circuit as represented by the positive loop, and during another part of the time work is being returned by the circuit to the source of electrical power. The average work absorbed by the circuit is now the difference between the average values of the positive and negative loops and is less than that which would be produced by an equal current which flowed in phase with the pressure.

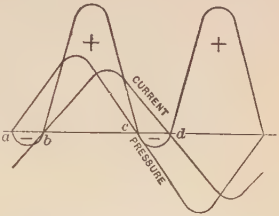

FIG. 164. — Power Loops when Current lags.

If the angle of lag happens to be 90° (in which case the current is halfway behind the pressure curve), as in Figure 165, the negative loops are then equal to the positive loops, and all the power absorbed by the circuit during one quarter period is returned during the next.

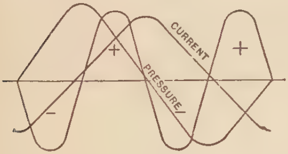

FIG. 165. — Power Loops when Current lags Ninety Degrees.

It is impossible to have quite 90° lag in a practical circuit because some power is always required to send a current through a circuit no matter how small the resistance may be. It must always be remembered that the amount of current flowing through a circuit at any instant is, by Ohm's Law, equal to the pressure divided by the resistance. The reason that in an inductive circuit the current does not apparently follow this law is because the *pressure acting to produce current at each instant is the difference between the pressure impressed* (which is shown in the curves) *and the counter-pressure of self-induction*, just as the current flowing through the armature of a direct current motor is equal to the difference between the impressed and the counter-pressures divided by the resistance of the armature.

**238. Measurement of Power in an Alternating Circuit.** — When an alternating current flows through a circuit which does not have any self-induction, the current loops and pressure loops are in unison as is illustrated by the curves, *AbCdE* and *ABCDE*, in figure 161. In this case we can measure the power which is used in the circuit by an alternating current voltmeter and an electrodynamometer, because these instruments measure the effective pressure and the effective current, and the two readings multiplied together give the power used in the circuit.[1] We can, therefore, *measure the power used in an incandescent lamp, which is operated on an alternating current circuit by means of an alternating current amperemeter and an alternating current voltmeter*, exactly in the same way that we would measure the power used by it when operated on a continuous current circuit.

If a coil of wire, having an iron core, is substituted for the incandescent lamp, the current loops are caused, by the effect of self-induction, to lag behind the pressure loops, and *we are not able to measure the power used in the coil by an amperemeter and a voltmeter*, as we did in the case of an incandescent lamp, *because, in this case, the product of the effective current and the effective pressure is not equal to the power.* The actual power used in the circuit is less than the value given by the product of the effective current and pressure.[2] *At* EACH INSTANT *the power consumed in the circuit is equal to the product of the current and the pressure at that instant*, exactly as is the case when the current and pressure loops are in unison; but *when the current lags behind the pressure, the* TOTAL POWER *consumed is less than would have been used in sending the same current under the same pressure through a circuit without self-induction.*[3]

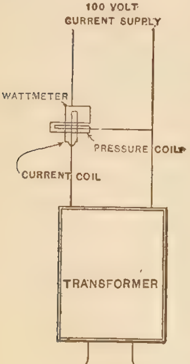

FIG. 166. — Connections of Wattmeter for measuring Power expended in Core of Transformer.

The moral of this is: do not try to measure the power used in any alternating current circuit, which has appreciable self-induction, by an amperemeter and a voltmeter. For instance, if the alternating current flowing in the primary coil of a transformer is measured and its value is multiplied by the alternating pressure which causes the current to flow, the product does not represent the power used by the transformer.

The power used when an alternating current is caused to flow through a circuit which has self-induction may be measured by a proper wattmeter; such, for instance, as that made out of an electrodynamometer, explained in Article 187. The indications of such a wattmeter, when connected to the circuit as directed in Article 187, are directly proportional to the power used in the circuit, because *they are the* AVERAGE *of the values of the power given to the circuit at every instant.*

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[1] Article 229.

[2] Article 237.

[3] Article 237.

If it is desired to find out how much power is wasted in the iron core of an alternating current transformer, for instance, it can be quickly done by connecting up a wattmeter as shown in Figure 166; for then, if the wattmeter has been calibrated, its readings will at once give the power.

**239. Transformers.** — Alternating currents are widely used for the distribution of electric currents for the purpose of electric lighting, because it is possible to use a high pressure on the distributing lines and thus make a saving in the expense of wires, and the high pressure may be reduced with little loss of power by means of induction coils or transformers to a pressure which it is safe to use in houses.

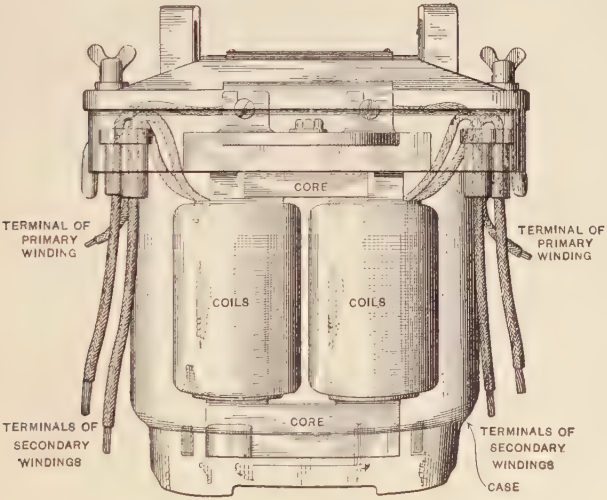
CORE
TERMINAL OF PRIMARY WINDING
TERMINAL OF PRIMARY WINDING
COILS
COILS
CORE
TERMINALS OF SECONDARY WINDINGS
TERMINALS OF SECONDARY WINDINGS
CASE

FIG. 167. — Skeleton View of Transformer.

These transformers consist of two coils, the primary and secondary coils, which have well-laminated iron cores made of strips or "stampings" of thin wrought iron laid together in such a manner that they make for the coils a core with closed ends, thus affording a complete magnetic circuit for the magnetism set up by a current in the coils. The primary coil usually consists of many turns of small wire, while the secondary coil consists of fewer turns of larger wire. The coils are carefully insulated with mica, rubber insulating tape, or other insulating materials, and the core is then built up by slipping the "stampings" into position.

Figure 167 gives a skeleton view of a transformer in the iron protecting case, which shows the positions of the core and coils in a clear manner. Figure 168 shows a view of a transformer mounted on an electric pole and connected to the electric light wires ready for use. As the transformer is exposed to the weather, the need of the protecting case is made evident. In some types of transformers it is usual to fill up the case with a heavy paraffine oil, which improves the insulation of the coils from each other. All transformers, from the smallest one, which has a capacity of one or two lights, up to several hundred horse power capacity, are very similar in construction. The various manufacturers make differences in the number and shape of the iron plates used in the cores, the sizes of wires and numbers of turns composing the coils, and in other details, but the greatest differences apparent to the sight are differences in the shapes of the iron cases. But though the real differences between the transformers are very small, even these small differences affect their usefulness very much.

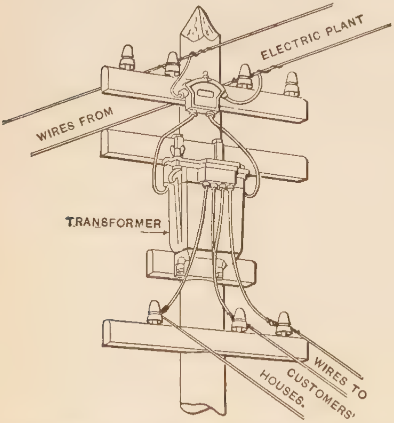

FIG. 168. — Transformer on Electric Light Pole.

**240. Transformer Iron Losses.** — The iron core of a transformer is magnetized first in one direction and then in the other by the alternating currents in the coils, and as the magnetic molecules are reversed there is a loss of power caused by hysteresis.[1] There is also a loss of power caused by eddy or foucault currents[2] which are set up in the iron core. These losses are quite small compared with the full load of the transformer (from 3 to 6 per cent); but when a great many lightly loaded transformers are operated all day long, as is done in many electric light plants, the total power lost may cause a great expense. The losses in the cores of transformers should, therefore, always be tested by electric light companies before the transformers are put into service, and if the losses are larger than they ought to be, the transformers should be sent back to the makers. The tests can be made by connecting up a wattmeter to a transformer, as shown in Figure 166. If the secondary circuit is left open, the reading of the wattmeter shows the loss of power caused by hysteresis and foucault currents. The following table shows approximately the amount of power which is lost in the cores of transformers of the best makes, when they are operated by alternating currents with a frequency of sixty periods per second: —

| CAPACITY OF TRANSFORMERS | LOSS IN CORE |
|---|---|
| 500 watts = 10 lights . . . . . | 25 watts. |
| 1000 " = 20 " . . . . . | 35 " |
| 2000 " = 40 " . . . . . | 45 " |
| 3000 " = 60 " . . . . . | 55 " |
| 5000 " = 100 " . . . . . | 75 " |
| 10,000 " = 200 " . . . . . | 125 " |

**241. Ratio of Transformation.** — In nearly all electric lighting plants where alternating currents are used in this country, the pressure generated by the alternator is between 1000 and 1200 volts, or 2000 and 2500 volts, while the pressure desired at the lamps is between 100 and 110 volts, or 50 and 55 volts. The transformer coils must be wound so that the number of primary turns has the same relation to the number of secondary turns as the primary pressure has to the desired secondary pressure. If the pressure is reduced from 1000 volts to 100 volts, there must be one-tenth as many turns in the secondary winding as in the primary, and if the pressure is reduced to 50 volts, the secondary winding must have one-twentieth as many turns as the primary. Since the power given out by a transformer is nearly as great as that given to it, the current in the secondary coil is nearly as many times greater than the primary current as the secondary pressure is smaller than the primary pressure.

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[1] Article 202.

[2] Article 201.

We have in transformers a most striking and wonderful example of the transfer of power from one electrical circuit (the primary circuit) to another circuit (the secondary circuit) *without the circuits being in any way electrically connected with each other.* The inductive action goes on just as well if the two coils of the transformer are separated by glass or mica as if they are wound close together. *It is only necessary for the magnetic circuit to be properly arranged so that the magnetism which is set up by the primary coil shall all pass through the secondary coil.* The action of transformers is really no more wonderful than the action of dynamos, but has the striking peculiarity that no mechanical motion is concerned in the transformations. In both machines the pressure is caused by change of lines of force in the generating coils, — in the dynamo by the conductors being moved through a fixed magnetic field, and in the transformer by setting up a variable magnetic field through the fixed secondary coils.

*Example A.* If a transformer has 1000 turns in the primary winding and gives a secondary pressure of 50 volts, when the primary pressure is 1000 volts, how many turns has the secondary winding? *Ans.* 50.

*Example B.* A transformer receives 1000 volts and 10 amperes at its primary. If the secondary pressure is 100, about how great will the secondary current be? *Ans.* 100 amperes (nearly).

*Example C.* The primary and secondary of a transformer respectively consist of 2000 and 100 turns. If the primary receives 10 kilowatts of energy at 2000 volts pressure, what will be the current (nearly) and the pressure of the secondary? *Ans.* 100 amperes (nearly) at 100 volts.

**242. Alternators.** — As already said, alternating current dynamos, or alternators, are built upon the same principles as continuous current dynamos, but the armatures are commonly wound in coils which are connected in series, and the two ends are brought to separate collecting rings. The field magnet usually has as many poles as there are coils on the armature, and *the number of alternations of the current per minute is equal to the number of poles in the field magnet multiplied by the number of revolutions made by the armature per minute.*

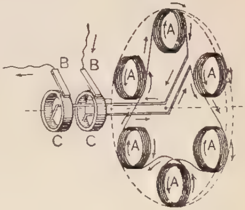

FIG. 169. — Connections of Alternator Armature.

Figure 169 shows a diagram of the connections of an alternator armature. The coils marked *AA* are armature coils and the rings marked *CC* are the collecting rings on which the brushes *BB* rub. The arrows show the way the current flows through the armature. Figure 170 shows the way the magnet poles are arranged for an alternator having an armature of the form shown in Figure 169. This arrangement of the armature and fields was formerly quite common in foreign alternators.

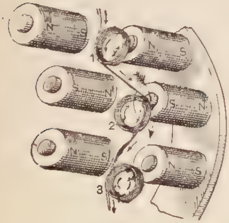

FIG. 170. — Fields of Alternator.

In this country the coils are usually laid in grooves cut in a drum armature core. Figure 171 shows the way in which coils are sometimes fixed in the grooves.

Since no commutator is required with an alternator, it is not necessary for the armature to revolve, and the field may be revolved instead. In this case, the magnetizing current is carried to the field windings through collector rings, and the armature terminals are connected

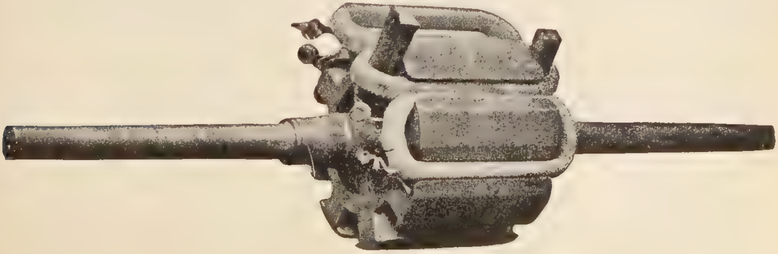

FIG. 171. — The Construction of an Alternator Armature.

directly to the circuit. It is also possible to build alternators in which neither the field nor armature revolves, but in which keepers of iron are moved so as to make and break the magnetic circuit of the field magnets and thus cause currents to be induced in the stationary armature. Such machines are called **Inductor Alternators**.

*Example A.* What is the number of alternations per minute set up by an alternator which has 8 poles and the armature of which revolves at a speed of 1200 rev. per minute? *Ans.* 9600.

*Example B.* What is the frequency of an alternator which has 10 poles and a speed of 1000 rev. per minute? *Ans.* $83\frac{1}{3}$.

*Example C.* At what speed must an alternator, having 8 poles, run to give a frequency of 80 periods per second? *Ans.* 1200 rev. per minute.

**243. Field Excitation.** — The field magnets of an alternator must always be excited by a continuous current, which is usually generated by a separate, small, continuous current dynamo called an **Exciter**. An exciter is shown alongside of the alternator in Figure 172. When an

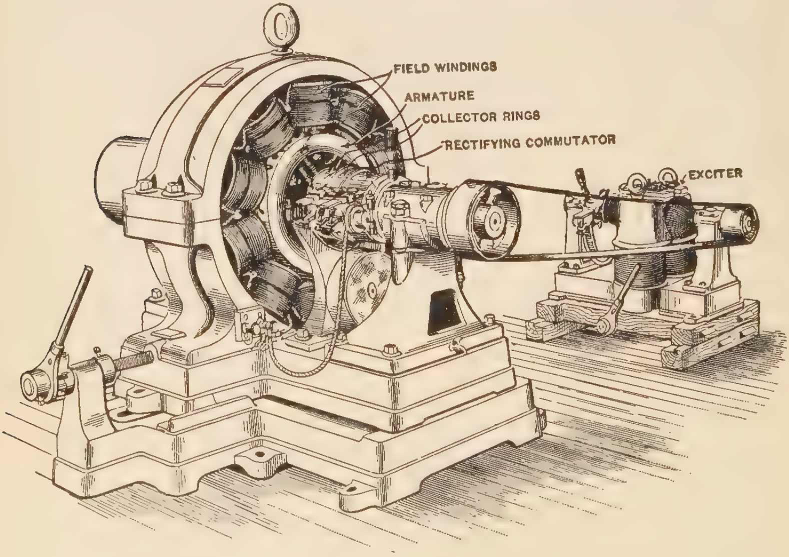

FIG. 172. — Alternator and Exciter.

alternator is loaded, the pressure at its terminals will decrease in a way that is analogous to that explained with reference to shunt-wound direct current dynamos.[1] To keep the pressure at proper value, therefore, it is necessary to have a hand regulator or rheostat in either the field of the exciter or alternator, or both.

The pressure may be kept reasonably constant, without much hand regulating, by rectifying a portion of the armature current by means of a commutator and causing it to pass through a few turns of wire on the field magnet. This excitation is in addition to that furnished by the exciter. Such an arrangement is called **Composite** excitation, and is similar in effect to compound winding[2] in direct current machines. The rectifying commutator is shown in Figure 172, just in front of the collector rings.

**244. Alternators in Parallel.** — Alternators cannot be worked in parallel with each other with the ease which is possible with continuous current dynamos. If two similar shunt-wound continuous current dynamos are to be connected in parallel, they are simply brought to their usual speeds, and their field magnetization is adjusted until the two machines produce the same pressure. They may then be connected in parallel and will work together very well. When two alternators are to be connected in parallel, it is necessary not only to make their pressures equal, but to *bring them to exactly equal frequencies* or to **Synchronism**, and also to arrange them *so that the current loops given by the two machines are in exact unison or* **Step**. On account of the difficulty in the way of properly **Synchronizing** and **Stepping** alternators, they are not usually operated in parallel in this country; though parallel operation is rapidly becoming less uncommon.

**245. Synchronous Motors.** — If an ordinary alternator is brought to synchronism with another machine, it may be run by the latter as a motor, but it will not start itself, as would a continuous current motor, nor is it possible to excite the field magnets of the motor from the alternating current circuits. It is, therefore, not convenient to use such machines, called **Synchronous Motors**, for common purposes.

Such machines are not self-starting, because the rapidly alternating currents first give a pull in one direction and then a push in the other.

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[1] Article 210.

[2] Article 210.

After the machine has been brought up to synchronism, however, the coils move from one pole piece to another as often as the current changes direction, thus making a tendency to turn constantly in one direction. Such motors have been arranged to be started by a small steam engine, a storage battery driving the exciter, or other very cumbrous means, but in recent years it has been found possible to build small alternating current induction motors or to put special windings upon the machines, which perform the starting duty. Polyphase currents, which will be dealt with in the next article, have done much toward making such motors available.

**246. Polyphase Currents.** — A second set of windings may be placed on an alternator armature, with the centres of its coils halfway between the first set (as, for instance, if another winding were put on the armature shown in diagram in Figure 169, with its coils between those shown in the figure); then the currents generated in the second set of coils have their maximum points just one-quarter of a period after the currents in the first winding. That is, the two currents have a difference of phase equal to quarter of a period, or 90 degrees.

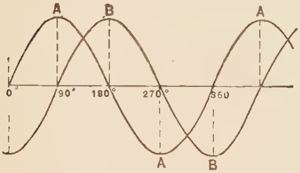

FIG. 173. — Diagram of Currents in Two-phase System.

The relation of these two currents to each other is shown in Figure 173, where the curves *A* and *B* represent the two current waves. These two currents may be used separately, or they may be used together as a **Two-phase** system with the two currents carried in circuits composed of three wires very much as the three wires compose the circuits of the three-wire system for continuous current distribution, which is described in a later chapter.

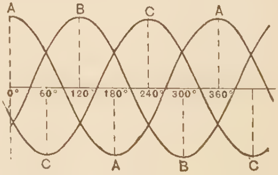

FIG. 174. — Diagram of Currents in Three-phase System.

Instead of two windings, three separate windings may be placed on the armature in such a way that the three currents produced in them differ from each other in phase by one-third of a period, or 120°. The relations of these currents are illustrated in Figure 174, where the curves *A*, *B*, and *C* represent the three current waves. These currents may be used separately or they may be used together as a **Three-phase** system with the three currents carried in circuits composed of three wires. In this case, if the three dots marked *a*, *b*, and *c*, in Figure 175 represent the cross sections of the three wires, then current *A* is carried in the circuit composed of the wires *a* and *b*, current *B* is carried in the circuit composed of the wires *b* and *c*, and current *C* is carried in the circuit composed of the wires *c* and *a*.

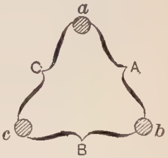

FIG. 175.—Diagram of Circuits for the Individual Currents of Three-phase System.

Either a two-phase or three-phase alternator which is arranged to furnish currents to three wires only, requires three collecting rings, though if the currents are to be used separately, four and six rings may be used. Two-phase and three-phase systems are frequently called **Polyphase** or **Multiphase** (many-current) systems, and the motors which are ordinarily operated on polyphase systems are called **Induction Motors.**

Polyphase alternators may be used as synchronous polyphase motors under conditions similar to those already explained for single-phase machines.

**247. Induction Motors.**—The action of induction motors may be explained by reference to Figure 176, which is an illustrative diagram of a three-phase motor. The field magnet of the motor is a ring which is wound with three separate coils, *X*, *Y*, and *Z*, each of which is supplied with one of the currents of the three-phase system through the wires *a*, *b*, and *c*. Since the maximum values of the three currents which thus flow through the coils *X*, *Y*, and *Z*, follow one another with a phase difference of a third of a period, their maximum points appear to chase each other around the ring. The magnetic effect of each coil at every instant is proportional to the current flowing in it, and the combined effect of the three currents sets up a

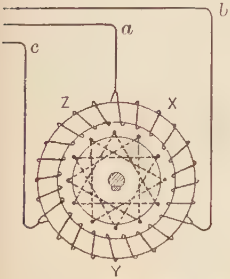

FIG. 176.—Illustrative Diagram of a Three-phase Motor.

magnetic field which rotates around the ring along with the maximum values of the currents.

The space inside of the field ring is occupied by an armature which consists of a grooved drum made of iron disks. Insulated copper rods are laid in the grooves, and the rods are all connected together by end rings, as in Figure 177, or they are connected in sets, as indicated by the dotted lines in Figure 176.

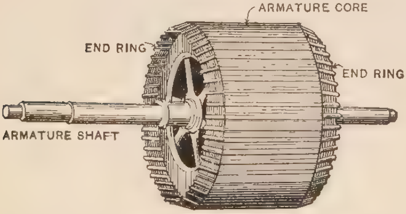

FIG. 177. — Armature of Induction Motor.

The rotating magnetic field set up by the currents in the windings *X*, *Y*, and *Z*, induces currents in the armature conductors, and these in turn, on account of the reactions between currents and a magnetic field explained in Article 207, cause the armature to revolve nearly in synchronism with the rotating field. This motor speed is not quite in synchronism, however, as otherwise no current would be generated to react upon the field.

The armature, with the bars all connected together, as shown in Figure 177, is called a **Squirrel-cage Armature.**

**248. Rotary Converters.** — It will be remembered that the current in the armature coils of direct current machines is alternating and must be commutated if direct currents are to be generated.[1] Therefore, if connections are made to the opposite sides of the armature of a bipolar dynamo and are carried to collecting rings, alternating currents may be drawn off (see Fig. 178). Such a machine will generate both direct and alternating currents. If the machine is run as a direct current motor, alternating currents may be drawn from the collector rings, and in this manner direct currents may be transformed into alternating currents. Likewise, if the machine is run as a synchronous alternating current motor, direct currents may be taken from the commutator.

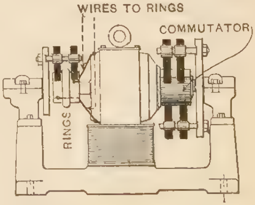

FIG. 178. — Rotary Converter.

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[1] Article 197.

Thus are alternating currents converted into direct currents. If three-phase alternating currents are desired, three rings are connected to three points, 120° apart, and if two-phase alternating currents are desired, four connections 90° apart are used.

In the case of multipolar dynamos, a set of connections must be taken to the rings for each pair of poles.

Much of the power from the great Niagara power plant is transformed by rotary converters into direct currents.

## QUESTIONS

48. What effect has current lag upon the power in an alternating current circuit?

49. Why does the product of effective current and pressure in an alternating current circuit not always give the power?

50. Will an effective current of 10 amperes under an effective pressure of 20 volts usually give the same power as a continuous current of 10 amperes under a pressure of 20 volts? Why not?

51. Would any power be given out in a circuit if the current and pressure were 90° apart?

52. Can a current actually have a lag of 90° behind the pressure that produces it?

53. Describe the power loops in an inductive alternating current circuit.

54. What pressures combine to furnish the pressure which drives the current through an alternating current circuit?

55. How can a voltmeter and amperemeter be used for measuring the power given by an alternating current to an *incandescent lamp?*

56. Why can the amperemeter and voltmeter be used for the purpose described in 55?

57. Why cannot an amperemeter and voltmeter be used for measuring the power in a self-inductive circuit?

58. Why will a wattmeter give the true power in either an inductive or non-inductive circuit?

59. What are transformers?

60. How are transformers made?

61. What advantage do transformers lend for transmitting power?

62. Why are the iron losses in transformers very serious to lighting companies?

63. How can transformers be tested to find the amount of iron losses?

64. What relations have the pressures, turns, and currents in the primary and secondary coils of a transformer?

65. Compare a transformer with a dynamo.

66. What is the difference between an alternator and a direct current dynamo?

67. How can the frequency of the current from an alternator be determined?

68. What is an inductor alternator?

69. How are the field magnets of alternators excited?

70. What is composite winding?

71. What precautions must be observed before alternators can be thrown in parallel? Why?

72. What is meant by saying that two alternators are in synchronism?

73. What is a synchronous motor?

74. Why are synchronous motors not self-starting?

75. Explain the words "polyphase" and "multiphase."

76. What are two- and three-phase alternators?

77. Describe a two-phase system of currents.

78. Describe a three-phase system.

79. What makes the magnetic field rotate in an induction motor?

80. Describe a squirrel-cage armature.

81. Why does the armature of an induction motor rotate?

82. How is the current in the armature of an induction motor produced?

83. What are rotary converters?

84. How are rotary converters made? How do they work?

# CHAPTER XVII

## ARC AND INCANDESCENT LIGHTING

**249. The Electric Arc.** — The **Arc Lights** which are so much a necessity to-day for illuminating the streets of cities and all large spaces which require a high degree of illumination, whether indoors or out, are the direct commercial outgrowth of a magnificent discovery which was announced shortly after 1800. This discovery was, indeed, nothing less than the possibility of producing the common **Electric Arc.** The discoverer of the electric arc, Sir Humphry Davy, the great English scientist, exhibited it on a grand scale in 1808 in a lecture before the Royal Institution in London, when he connected the electric circuit from a battery of two thousand or more cells through two pieces of charcoal and then gradually separated them. The result was an arch or "arc" of dazzling light between the charcoal tips such as had never before been artificially produced. Sir Humphry Davy's experiments created a great deal of interest, but the real usefulness of the electric arc was not seen until Faraday's later discoveries had laid the foundation for the development of the dynamo and the economical production of electricity.

The means for producing this arc of light are comparatively simple. When two pointed pieces of carbon (made from charcoal, coke, etc.) are joined to opposite poles of the circuit from a powerful generator of electricity and are touched together, a current flows between them. A considerable resistance exists where their points are in contact, and the points are heated by the current unless they are pressed very tightly together. If the contact is quite loose, the points become so hot as to cause the carbon to pass off as vapor. Now, if the carbon points are separated, the current continues to flow across the space between the points, which is filled with carbon vapor, forming the electric arc. Carbon vapor is a much better conductor of electricity than air, and the current can, therefore, be caused to flow across a space filled with it, though it could not readily be caused to flow continuously through the same space filled with air.

It seems strange to speak of the vapor of carbon, but the temperature of the electric arc is so great that it boils and vaporizes the most refractory materials. The vaporizing of any material is merely a question of temperature, and the vaporization of carbon, platinum, gold, iron, copper, etc., in the electric arc is just as simple as the conversion of water into steam (the vaporization of water) over a common coal fire. The vaporization of "refractory" materials like carbon, platinum, et cetera, simply requires a much higher temperature than that which is reached by the coal fire that is amply sufficient to boil water.

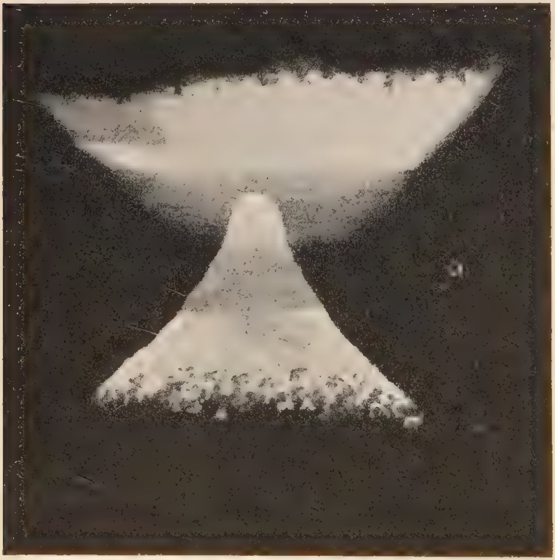

FIG. 179. — The Electric Arc.

After a direct-current arc has existed for a little time between the carbon points, they come to look very much as they are shown in Figure 179. Both points become quite hot and give off light, but the positive point (which is the upper point in the figure) becomes much hotter than the negative, and from it comes the greater part of the light of the arc. In an arc which is set up with a continuous current, carbon is carried off by the current from the positive point but not from the negative point. The positive point, therefore, becomes a little hollowed out on the end as shown in the figure. This hollow is called the **Crater** of the arc.

As the greater part of the light of the direct-current arc comes from this positive end or crater, the positive carbon in an arc lamp is almost always put at the top, in order that the light may be thrown downward. When an arc is set up with an alternating current, both points become somewhat crater-like and light is given off about equally from the two points.

FIG. 179 *a*. — The Electric Arc produced in an Open Arc Lamp by a Direct Current.

Since the arc is surrounded by air, the carbon of which the points are composed is gradually burned up, and if the carbons are fixed in position, the arc grows longer and longer until its resistance becomes so great that the current cannot pass through it; the current then stops and the arc goes out. Since carbon is carried away from the positive point, but not from the negative point, the former wastes away in a direct-current arc at a rate which is just about double that of the latter. The two carbons of an alternating-current arc waste away at approximately equal rates. The expenditure of carbon grows larger with the current and is approximately independent of the size of the carbons, so that carbons of large diameters have a "longer life" than smaller carbons.

FIG. 179 *b*. — The Electric Arc produced in an Open Arc Lamp by an Alternating Current.

**250. Arc-lamp Mechanism.** — In order that the electric lamp may be used for commercial lighting, an automatic device must be used to keep the carbons fed toward each other as they waste away, so that the arc shall always have the proper length. This is included in the mechanism of what is known as an **Arc Lamp**. This consists of a case which contains the feeding mechanism, below which is a frame to support the lower or negative carbon and a glass shade.

The feeding mechanism has two duties to perform: —

1. To separate the carbons, or strike the arc, when the lamp is thrown into circuit.

2. To regulate the movement of the upper or positive carbon downward toward the negative one as the carbons wear away.

The lower carbon is usually clamped solidly at the bottom of the lamp frame, and the upper one is clamped at the end of a polished brass **Carbon Rod**, the motion of which is controlled by the mechanism.

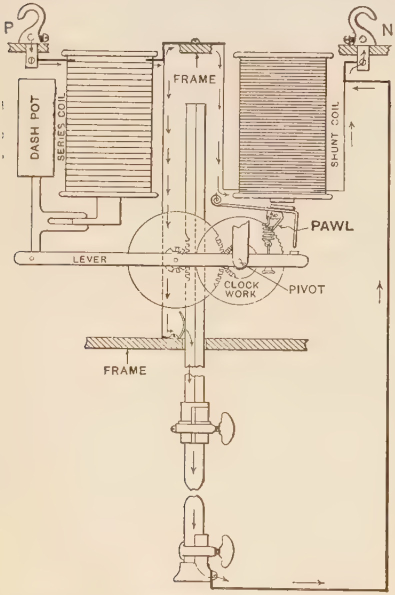

FIG. 180. — Diagram of Clock-work Arc-lamp Mechanism.

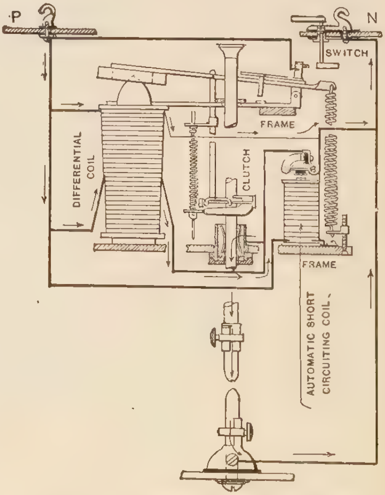

FIG. 181. — Diagram of Clutch Arc-lamp Mechanism.

Figures 180 and 181 show familiar forms of arc lamps, intended for use in series circuits. The mechanism of such lamps is usually caused to operate by the opposing action of two electromagnets, or an electromagnet and a spring. The windings of one of these are composed of a few turns of comparatively coarse wire which are connected directly into the circuit in series with the arc. The windings of the other magnet are made of many turns of comparatively fine wire which are connected as a shunt to the arc. The two electromagnets may be plainly seen in Figure 180. In some lamps, both windings are put on the same magnet.

The purpose of the windings is the same in the two arrangements, and may be explained by reference to Figure 180. A brass lever which runs across the lamp carries an iron armature or plunger at one end. The armature is in such a position that it is attracted by one of the two electromagnets, and the lever is attached to the mechanism which controls the carbon rod. The lamp is **Trimmed** or **Carbonned** with the tips of the two carbons resting against each other. When the lamp is thrown into circuit, the full current of the circuit flows through the **Series Winding**, and the lever is lifted by the attraction of the **Series Magnet**. This causes the mechanism to raise the carbon rod sufficiently to **Strike** the arc. As the carbon burns away, the electric pressure between their points becomes greater, so that the current in the **Shunt Coil** increases. The armature of the shunt coil is attracted more and more strongly, until the clutch or pawl releases the carbon rod sufficiently for it to slide slowly downward, and thus **Feed** the positive carbon toward the negative.

In order that the lamp may burn smoothly and quietly it is necessary for the feeding mechanism to keep the carbons at a uniform distance apart while the lamp is burning. This can only be accomplished when the magnetizing coils are properly balanced against each other, and the strength of the spring, which acts on the lever, is properly adjusted. Even when all the adjustments are exactly right, arc lamps will not burn well unless the carbons are of uniform quality. In some arc lamps the carbon rod is controlled by a clock-work, which in turn is controlled by the **Differential Magnets** (Fig. 180), while in others a simple clutch is caused to act on the carbon rod by the magnets (Fig. 181).

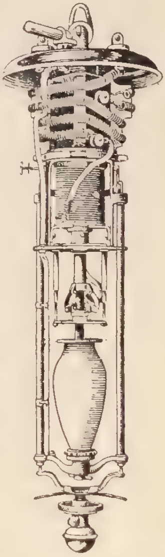

FIG. 182. — Enclosed Arc Lamp with Cover removed.

In another style of lamp the differential action of the magnets is not utilized, but the pull of the shunt magnet is arranged to act against the force of a spring. This style of lamp is trimmed so that a little space remains between the carbon points.

**251. Enclosed Arc Lamps.** — It has been found very recently, about 1895–1896, that an arc can be successfully maintained in a fairly tight globe; and that by so excluding the air a pair of ordinary carbons can be made to burn from 60 to 125 hours. The **Enclosed** lamp (Fig. 182) also burns with a steadier light than the **Open Arc**, so that it is more desirable for indoor lighting.

FIG. 182*a*. — Electric Arc produced in an Enclosed Lamp by a Direct Current.

This lamp uses about the same power per candle power, but about twice the pressure and one-half the current required by the open arc. The lamps are largely used on constant pressure systems though they are coming into use for series street lighting. The mechanism may be like that described above, but series coils alone, acting against a spring, instead of differential coils, are generally used. The enclosing globe must not be absolutely air tight or it will explode, and indeed it would be difficult to make it air tight, since the upper carbon must be fed through an opening in the top plate.

**252. Candle Power and Operation of Arc Lamps.** — As a general rule, arc lamps are connected in series[1] so that the same current passes through all. This current is usually furnished by a series dynamo which automatically keeps the magnitude of the current constant. The constancy of the current is a very important element in the proper regulation of the lamps. Nearly all open arc lamps are now adjusted so that the *pressure* required to pass the current through the arc is from 45 to 50 volts. If the pressure is made smaller, the arc becomes shorter and gives less light, and it produces a continuous hissing or frying sound. If the pressure is greater, the arc **Flames** and flickers, which makes it unsatisfactory. The current used usually approximates 9.6, 6.5, or 4 amperes.

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[1] Article 102.

Arc lamps which are intended to be used with 9.6 amperes are usually spoken of as 2000 nominal candle power or 450 watt lamps, while those intended to be used with 6.5 and 4 amperes are usually called 1200 nominal candle-power and 600 nominal candle-power lamps.

A candle power is equal to the light given off by a sperm candle of fixed size and form. The actual useful candle power given off by the lamps is much less than the figures given in the last paragraph, and in fact the light given off in different directions varies from a hundred candle power or thereabouts to nearly the rated value of the lamp. Figure 183 shows, by the curve, the amount of light given off by arc lights in different directions when using various currents.

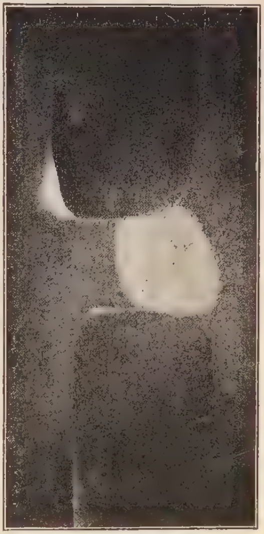
FIG. 182*b*. — Electric Arc produced in an Enclosed Lamp by an Alternating Current.

The greatest amount of light is given off from direct-current open arc lamps at an angle of about 45° from the direction of the carbons. For this reason the best effect may be gained from arc lights used in illuminating streets by hanging them from 25 to 35 feet from the ground over the centres of streets, or by mounting them at street corners on tall poles such as that shown in Figure 184. Inside of buildings they are usually hung from small boards fastened to the ceiling. An enclosed switch is usually placed in arc lighting wires where they enter a building.

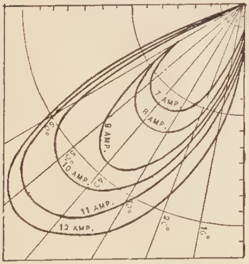

FIG. 183. — Candle-power Curves.

As the carbons which are ordinarily used in open arc lamps are of such a length that they will only burn for seven or eight hours, **Double Lamps**, which have two sets of mechanism and two carbon rods, as shown in Figure 184, are used for all-night lighting. These consist of a modified mechanism which controls two carbon rods, one of which does not come into service until the carbons held in the first have burned out.

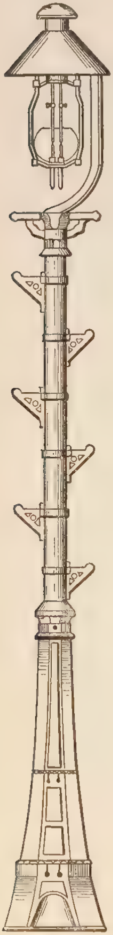

FIG. 184. — Street Lamp-post for Arc Light.

The carbons that are ordinarily used vary from $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter, and are usually coated with copper to reduce their resistance. The positive carbon is about 12 inches long and the negative is about 6 inches long. The carbons are made from finely ground coke or lamp-black which is mixed with syrupy compounds and then baked in moulds, or by some equivalent process. The copper coating is put on by electroplating. Oval carbons about 1 inch broad and $\frac{1}{2}$ inch thick have been used in single lamps for all-night burning.

**253. Arc Machines and Switchboards.** — The number of successful manufacturers of series arc-lighting machinery is comparatively small. The earliest to enter the business in this country, with commercial success, was the Brush Electric Company, and to this company is probably due the introduction of lamps with differential magnets, which are still so much used. The Brush arc-light dynamo is shown in Figure 185. Figures 186 and 187 show other types of arc-light dynamos. The regulation of these is performed by moving the brushes around the commutator, or shunting the field windings, so that the pressure is varied as lamps are cut into and out of circuit, and the current is thus always kept of constant value.

In order that the dynamos in a series arc-light generating station may be properly managed, it is necessary to have some arrangement by which any dynamo in the station may be connected to any one of the circuits which run out to the lamps. The number of dynamos and circuits may be quite large in a plant which is located in a large city, and the arrangement that is usually used for the purpose is a switchboard (Fig. 188) fitted with a heavy spring jack for each wire leading to the lamp circuits. The spring jacks may be connected as desired by plugs and cords. The figure shows a switchboard arranged for three lamp circuits marked 1, 2, 3, and for three dynamo circuits marked *A*, *B*, *C*. Each dynamo is shown to be connected to a lamp circuit by means of plugs and cords. The amperemeters at the top of the switchboard are connected in the dynamo circuits and serve to show the dynamo attendant whether or not the machines are regulating properly.

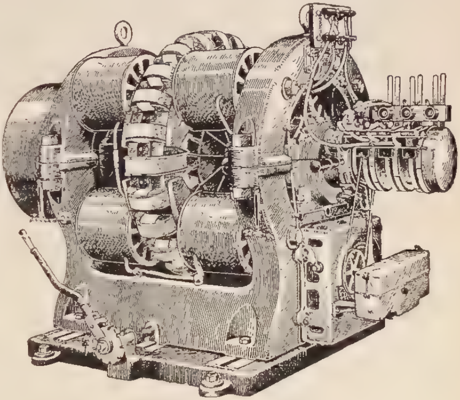

FIG. 185. — Brush Arc-light Dynamo.

**254. Incandescent Lighting.** — Illumination by arc lights is very satisfactory in streets or open spaces out of doors or in large rooms such as shops or halls, but its intense brilliancy causes it to cast dense shadows which totally unfit it for satisfactory use in general indoor lighting. Its unavoidable flickering and occasional hissing also make it unsatisfactory for general use in small rooms. If the faults of the arc when used for general indoor lighting were not so evident, the use of small arcs in office and house lighting might have been attempted as early as

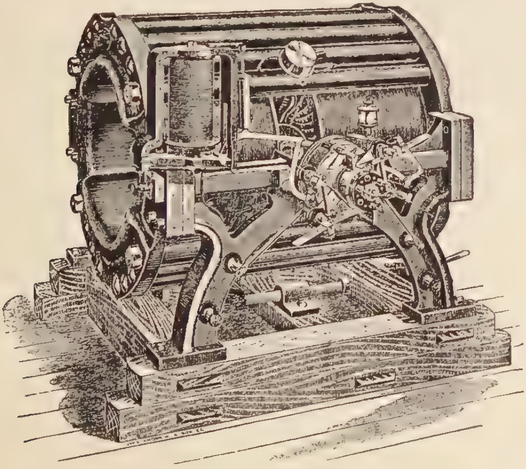

FIG. 186. — Thomson-Houston Arc-light Dynamo.

1880, by which time the arc lamp had begun to prove its value for outdoor lighting. The disadvantages of the arc for general illumination had become known by that time, and inventors were using every effort to find some substitute.

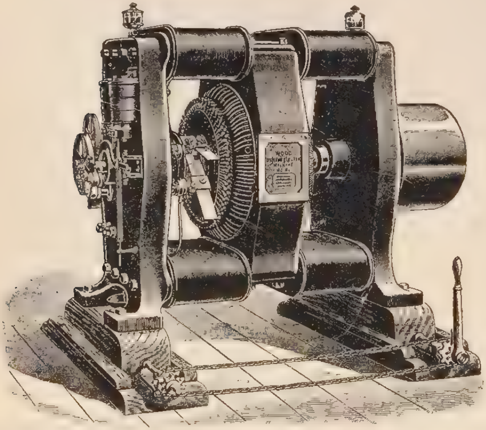

FIG. 187. — Wood Arc-light Dynamo.

Many years earlier, inventors had made electric lamps which consisted of a loop of wire made of platinum or iridium, two metals which melt only at exceedingly high temperatures, and in which the light was produced by heating the wire white hot, or to **Incandescence**, by means of a current. The light was, therefore, produced by means of the great heat caused in the wire when a current flowed through the high resistance of the wire.[1] This is a case where the $C^2R$ loss was turned to a useful account, but the lamps were not successful, though the same principle is used in the incandescent lamps of to-day.

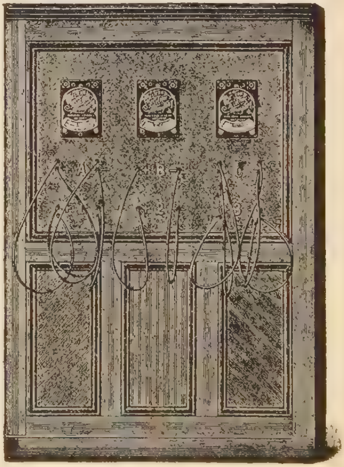

FIG. 188. — Arc-light Switchboard.

Just previous to 1880 many prominent inventors, including Edison, Maxim, Farmer, Sawyer, and Man in this country, and Swan in England, were making every effort to construct a satisfactory lamp to operate by the incandescence of some material. It was found that loops of platinum and iridium were unsatisfactory because they soon melted or gave out when continuously subjected to the high temperature which is necessary to produce a satisfactory light. The only conducting material which would stand the high temperature of incandescence was found to be carbon. Unfortunately carbon burns away when heated to a high temperature in the air, and, therefore, could not be used in a lamp in the same way that metallic wires had been.

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[1] Article 112.

**255. The Carbon Filament Lamp.** — As early as 1845 a lamp had been made in which a thin stick of carbon was enclosed in a glass globe from which the air had been exhausted. This lamp produced an excellent light, as the carbon could not burn away in a vacuum, however hot it became, but no satisfactory arrangements then existed for making proper carbon sticks or for exhausting the air from the glass globes. Shortly before 1880 the inventors turned from their efforts to make a satisfactory loop from a metal wire, to make another attempt to use carbon. By 1880 Edison, Sawyer and Man, and Swan had made lamps which produced light through the incandescence of a thin strip or **Filament** of carbon.

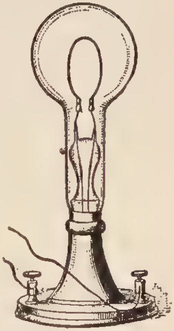

FIG. 189. — Early Edison Incandescent Lamp.

The lamp made by Edison looked very much like the incandescent electric lamps of the present day, and it is no doubt to his industry and ingenuity that we owe the introduction of the cheap and economical form of incandescent lamp which we now use. One of Edison's early lamps is shown in Figure 189. The globe or **Bulb** of the lamp contained a filament of carbonized paper in an arched or horseshoe form. The ends of the carbon horseshoe were connected to short pieces of platinum wire which passed through the glass of the bulb. By means of these wires a current could be led to the filament. The bulb was **Exhausted** (that is, the air was removed) by means of a form of mercury air-pump, which is used in a modified form for the same purpose at the present day, and which is capable of producing a very perfect vacuum.

**256. Exhausting Incandescent Lamps.** — Figures 190 and 191 show the two forms of air-pumps which have been commonly used in exhausting lamps. These are often called vacuum pumps because they are used to produce a vacuum. The first is called the **Geissler Pump** after its inventor, who was also the maker of the vacuum tubes known as Geissler tubes, which display such pretty color effects when an electric spark is passed through them. The pump shown in the second figure is called a **Sprengel Pump**, also after the name of its inventor.

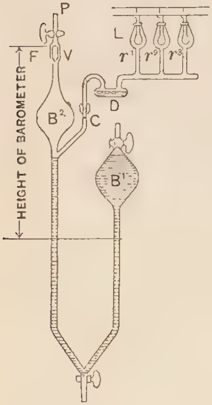

FIG. 190. — Geissler Pump.

The operation of the Sprengel pump (Fig. 191) is quite similar in principle to the operation of some injectors. The mercury is allowed to flow in a jet through the nozzle *J*, and air is drawn from the lamps by the suction of the drops of mercury rushing past the end of the lamp tap. The Geissler pump is more complicated in its action, but briefly, the bulb $B^2$ is filled with mercury, which is then drawn out, leaving a vacuum, which in turn draws air from the lamp. This process is repeated again and again until a satisfactory degree of exhaustion is produced.

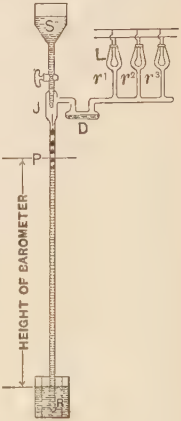

FIG. 191. — Sprengel Pump.

**257. The Production of Carbon Filaments.** — The carbon filaments of incandescent lamps are frequently made from bamboo strips or from silk or cotton threads, though recently they are more usually made by squirting a glutinous substance through a small aperture and hardening it in a vessel of water. These are converted into carbon by baking, in very much the same way that wood is converted into charcoal in a kiln. The material is first made into exactly the proper size to produce a filament. After proper treatment which reduces the thread to a cellulose or pulplike form, it is bent around blocks of carbon and is packed in a crucible filled with powdered carbon. The material is then converted into black carbon hairpins by baking for many hours. The hairpin form comes from the shape of the blocks around which the material was wrapped.

To bring the filaments to the proper resistance and at the same time put them into condition to stand the strain of the high temperature of "burning," they are commonly "treated" by a process which deposits very hard gray carbon upon their surfaces. This treatment is usually termed "flashing," and consists in immersing the filaments in naphtha gas or petroleum and passing a current through them. The current heats the thin parts of the filaments to a white heat. This heat in turn decomposes the naphtha or petroleum, and carbon is deposited on the filament.

The filaments are then each mounted upon two short pieces of platinum wire which are sealed into a bit of glass. The connection between the carbon and the platinum is usually made satisfactory from an electrical point of view by means of a cement. The filament thus mounted is sealed into the bulb by a glass-blower in the way described in the next paragraph.

The bulbs are usually purchased ready made from a glass factory. One of these bulbs is selected and a piece of glass tube is connected to the top of the bulb. This serves as a handle for the workmen and also for connecting the lamp to the pump. The carbon filament is then inserted into the neck of the bulb, and the glass at the base of the carbon is so carefully welded into the glass base of the bulb that the union becomes absolutely perfect. After exhausting,[1] the glass tube at the top of the bulb is sealed off and the lamp is complete. The wires passing through the glass are of platinum, because that is the only material now known that will maintain a tight joint. The little point usually found at the top of an incandescent lamp is the stub which is left when the glass tube is sealed off after the lamp has been exhausted.

**258. Lamp Bases and Sockets.** — For convenience in use, incandescent lamps are mounted on bases to which they are fastened with plaster. These bases contain two contacts which correspond to two contacts in a **Socket** which may be connected to an electric circuit. In Figure 192, *b* is the lamp bulb, *c* is the carbon filament, *ww* are the platinum leading-in wires, *j* is the cement connecting the carbon and platinum, *f* is the brass base which is attached to the lamp by the plaster *p*, *d* and *r* are the two contacts by which the carbon is brought into connection with the electric circuit when the lamp is inserted in a socket, and *t* is the point where the lamp was "sealed off" the pump. The bases used on lamps have various external forms depending upon the manufacturer, and the one shown in the figure is very commonly used.

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[1] Article 256.

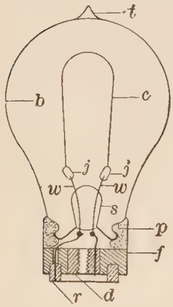

FIG. 192. — Diagram of Incandescent Lamp.

In order that incandescent lamps may be as conveniently turned on and off as gaslights, the sockets often contain switches as shown in Figure 193, which is a skeleton view of a socket. Where lamps are arranged to be controlled by wall switches, plain or **Keyless** sockets are generally used.

**259. Parallel and Series Connections for Electric Lamps or Motors.** — Incandescent electric lamps and electric motors are sometimes operated upon series circuits, but they are much more satisfactory when connected in parallel,[1] as is usually done.

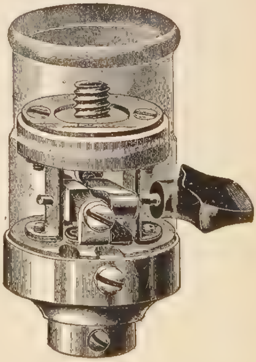

FIG. 193. — Skeleton Diagram of Lamp Socket.

The difference between the connection of lamps in parallel and lamps in series may be illustrated by comparing the methods of utilizing water power. Suppose a series of dams is placed in a stream and a mill is placed at each dam. The water which passes through the water-wheels of the first mill flows down to the second mill and passes through its wheels, and thus continues to flow through the wheels of one mill after another. The wheels of each mill are, therefore, turned by the same water that turns the wheels of every other mill. In order that this may be the condition, each mill must be located on a lower level than the one up stream from it. Then the total fall of the stream is so divided that each mill gets advantage of a proper proportion.

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[1] Article 103.

In series arc lighting the same current flows through all the lamps one after the other, and the total pressure at the dynamo is divided amongst the lamps. If an arc dynamo is capable of producing 1000 volts, it will operate twenty open arc lamps in series, since it takes about fifty volts to send the current through each arc. If a portion of the lamps are cut out of circuit, the pressure at the dynamo must be reduced or the current will increase above its proper value.

If, instead of dividing up the total fall of the stream so that each mill gets the benefit of a part, a large dam is built on the stream and the mills are located so that they all take water from the same canal and discharge water into the same tailrace, all of the mills get the benefit of the entire fall, but the water of the stream is divided between them in proportion to their needs, and their wheels are in parallel. The amount of water flowing through the wheels of each mill in this case is directly proportional to the work being done in that mill. If one mill is shut down, the gate through which water is admitted to the wheel is closed, and no water flows through. The water used by each mill is entirely independent of the amount used by the others.

In the same way, when electric lamps are connected in parallel the current flowing through each lamp is entirely independent of that flowing through the others, and simply depends upon the resistance of the lamp and the pressure at its terminals. When it is desired to cut out of circuit a lamp which is connected in parallel with others, its connection with the circuit is broken by a switch (Fig. 193) so that no current can flow through it. This is equivalent to closing the gate through which water enters a mill, as already explained.

When it is desired to shut down one of a number of mills in series, it evidently will not do to simply close the gates which admit water to the wheels, as that would prevent the water from flowing to the other mills, but it is necessary to arrange a short path for the water to flow around the mill which is shut down. In the same way, when it is desired to turn off an electric lamp which is operated in a series circuit, the lamp must be short-circuited as at *A* in Figure 194. Some special switches used on arc-lighting circuits short-circuit the lamp which is to be turned off, so that the main line is properly completed, and then also disconnect the lamp terminals from the line.

**260. Effect of a Change of Pressure on an Incandescent Lamp.** — Since the current which flows through incandescent lamps connected in parallel depends upon the pressure at the lamp terminals, and the light given by each filament depends upon the current flowing through it, the pressure at the terminals of the lamps must be kept perfectly constant, or they will not give a steady light. If the electrical pressure at the terminals of an incandescent lamp is changed, the light given off by the filament changes at a much faster rate.

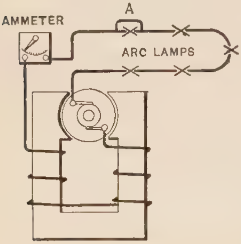

FIG. 194. — Illustration of Series Circuit with One Lamp cut out.

If a lamp, for instance, which is intended for a pressure of 110 volts and to give 16 candle power, is connected to a 105 volt circuit, the light which it gives is no more than about 12 candle power and is of a poor red color. If the same lamp is connected to a 115 volt circuit, the light which it gives becomes about 20 candle power and is of a brilliant whitish color. The great candle power and whiteness of the light in the latter case shows that the filament is so excessively hot that even refractory carbon cannot last long under the strain, and the filament will soon give out.

The length of time during which the filament of an incandescent lamp will last — that is, *the* **Life** *of the lamp* — decreases very rapidly as the temperature at which the filament burns is increased above its proper value. On the other hand, the power required to produce light increases as the working temperature of the filament decreases. It should, therefore, always be the aim to operate incandescent lamps at the exact pressure for which they were designed.

**261. Distributing Wires.** — We have already seen that there is always a loss of pressure when an electric current flows through a wire — this loss being equal to the product of the amperes of current and the resistance of the wire.[1] Consequently, when a number of incandescent lamps in parallel are connected to a circuit at some distance from the dynamo which supplies the current, the wires of the circuit must be quite heavy in order that the loss in pressure shall not be too great.

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[1] Articles 92 and 106.

When incandescent lamps and motors are connected to wires which lead from a central generating station, it is common to allow a loss of pressure or "drop" amounting to as much as ten to twenty per cent of the dynamo pressure when all the lamps are turned on. The circuits must be so arranged that all the lamps shall be fed with current at as nearly the same pressure as possible, and if the "drop" is allowed to be greater than twenty per cent, this becomes a difficult matter.

When the "drop" in the wires is too great, it is also difficult to regulate the dynamos so that the pressure at the lamps shall not vary when lamps are turned on or off. It is easy to see that every lamp which is turned on or off changes the current flowing through the wires of the circuit, and therefore changes the pressure lost in the wires between the dynamos and the lamps. In plants which are confined to a single building the "drop," when all the load (lamps and motors) is turned on, is usually made to be from two to eight per cent of the pressure at the dynamo.

The transmission of power to the lamps will be dealt with at greater length in a following chapter.

## QUESTIONS

1. Who first produced the electric arc? When?

2. Why does an arc continue to burn after the carbons are separated a little?

3. What is the crater of an arc? What makes it?

4. Why is the positive carbon put above the negative when the electric arc is used for lighting?

5. Does the positive carbon burn more or less rapidly than the negative?

6. What duties must an arc-lamp mechanism perform?

7. Explain how the two coils of an arc-lamp mechanism keep the arc of the proper length.

8. What is a differential magnet?

9. Describe the enclosed arc lamp.

10. How does an enclosed arc lamp differ from an open one?

11. What are the ordinary pressures, currents, and candle powers of open arc lamps?

12. What is a candle power?

13. What is the character of the distribution of the light around a direct-current arc lamp?

14. What are double arc lamps?

15. How are arc-light carbons made? What sizes are commonly used?

16. How are arc dynamos regulated to give constant currents?

17. Describe an arc-lighting switchboard.

18. What happens if the voltage of an arc lamp is too high? If too low?

19. Give a short history of the development of the incandescent lamp.

20. Why is carbon used for incandescent lamp filaments?

21. Why is the bulb of an incandescent lamp exhausted?

22. How are lamp bulbs exhausted?

23. How are carbon filaments made?

24. What is flashing?

25. Why is platinum used for the conducting wires which lead in through the glass of incandescent lamp bulbs?

26. Describe an incandescent lamp base and a socket.

27. Why must the pressure of an arc dynamo vary with the number of series lamps in circuit?

28. Give a water analogy to a series system of lighting.

29. Give a water analogy to a parallel system of lighting.

30. How can a series lamp be cut out of circuit? How can a parallel lamp?

31. Why is it absolutely necessary to work incandescent lamps at their proper pressure to give satisfaction?

32. Why must the "drop" in the conductors of parallel lighting systems be kept small?

33. How can the "drop" in the wires be kept small?

34. What is the maximum "drop" that should be allowed in a parallel system of lighting?

# CHAPTER XVIII

## POWER STATIONS, THE ELECTRIC RAILWAY, AND OTHER APPLICATIONS OF MOTORS

**262. Development of the Central Station.**—When, in 1884, Mr. J. E. Gordon wrote his book called "A Practical Treatise on Electric Lighting," he filled the rather large volume with descriptions of dynamos and electric lamps made in forms which are now nearly all discarded, but at that time there was little else to write about in the field of electric lighting. There were at that time no great electric lighting plants such as we have to-day, nor were there any even to be compared with those in existence only five years later than the date of the book. With the same courage and optimism which led him to say in 1881, "the day will come when gaslight will be as obsolete as wooden torches, and when in every house the incandescent lamp will have replaced the gas-jet," Mr. Gordon left space in his book for a chapter called "Central Station Lighting." Under the heading was only the single paragraph, "I had intended to write a long chapter with the above heading, but for various reasons I am not yet prepared to do so. I have, however, left in the heading for the convenience of inserting such a chapter in a future edition of this book, should one ever be required."

At the present time, less than two decades later than the time when Mr. Gordon wrote, we have numbers of books upon the subjects of electric lighting and electric plants, and the progress of this period has been so enormous that many of the descriptions in Gordon's book seem to belong to another age. We may say, indeed, that they do belong to another age, for a decade constitutes an epoch in the history of the modern development of electrical apparatus.

It is instructive and interesting to see the way in which electric plants have developed since 1884. This is best shown by figures representing plants which were built at different periods. Figure 195 shows one of the earliest central-station electric-light plants of the world, the first Edison central station for the public supply of electric current, which was located at Appleton, Wis., in 1881. At the left hand of the figure is shown the exterior of a small frame shanty in which this plant was located, while at the right hand of the figure the shanty is shown with one side removed, so that the plant with its dynamo, pulleys, and belts is exposed to view.

This plant was operated by water power, and the gears on the water-wheel shaft used to drive the counter shafts to which the dynamo was belted are shown in the centre of the figure. The plant was put in operation before the day of the three-wire system,[1] and it therefore had only one dynamo. Behind the dynamo in the picture the regulating and indicating apparatus are vaguely seen.

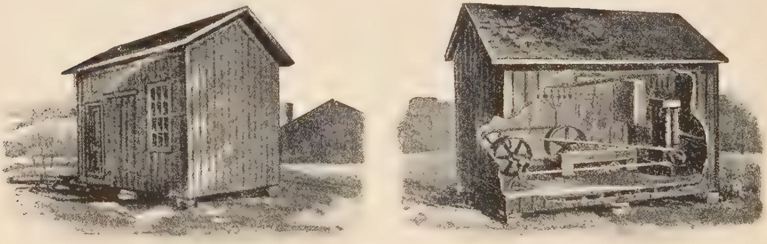

FIG. 195. — Early Edison Electric Light Central Station.

A peculiar and interesting point in the picture is the dynamo, which, it will be noticed, looks quite different from those illustrated in preceding chapters. This dynamo has a spindling, lean appearance which forms a decided contrast to the chunky, substantial form of the modern dynamos. The field magnets of the dynamo, which is bipolar, are divided into several legs, as though there were several horseshoe electromagnets attached to the poles. At the time these machines were built this was supposed to be the best way of constructing dynamos, but the modern construction with a single short horseshoe has been proved to be the best form for bipolar dynamos with salient poles.

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[1] Article 334.

One of these so-called "spindle-shank" dynamos which was used by Mr. Edison in his first public exhibition of incandescent electric lights at Menlo Park in 1880 is now in the dynamo collection of the University of Wisconsin, where it makes a striking contrast to the appearance of the substantial later dynamos of equal capacity which stand by its side. Notwithstanding its peculiar appearance, the old dynamo is still good for any reasonable service, and, indeed, it had been doing almost daily work from 1880 up to the time of the World's Fair in Chicago, where it was exhibited, and from whence it was forwarded to its present place.

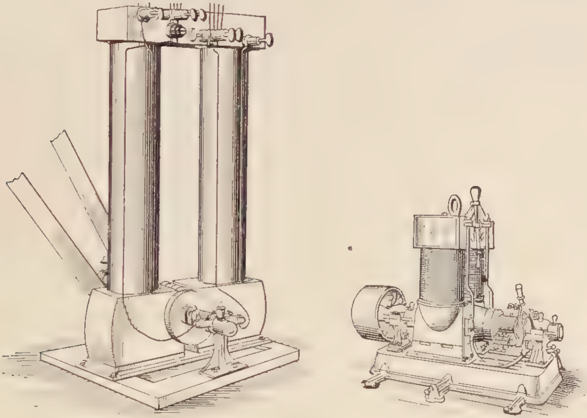

FIG. 196. — Old Style and New Style Bipolar Edison Dynamos.

One of the old spindle-shanks, with a later dynamo of the same capacity beside it, is shown in Figure 196.

The plant which is now located at Appleton, Wis., is as great a contrast to the original one as the old dynamo is to modern machines. It now contains several fine dynamos with excellent regulating devices, housed in a substantial building, which are used to furnish current to incandescent and arc lights, stationary electric motors, and to electric cars.

**263. The Pearl Street Station.** — The great landmark in electric central stations, the Pearl Street station of New York City, was operated continuously from the fall of 1882 until 1894, when it was destroyed by fire. It has now been replaced by a magnificent station, to which reference will be made later. Figure 197 shows one of the then great "Jumbo" dynamos which were used in this station, each directly coupled to its own engine. Each one of these dynamos had a capacity of 1500 sixteen-candle-power incandescent lamps, and occupied not less than 175 square feet of floor space. It is interesting to compare the "Jumbo" machine with one of the latest triumphs of electrical engineering, the great "steam dynamo" shown in Figure 198, which has a capacity of 20,000 sixteen-candle-power incandescent lamps, and occupies but little more floor space than the "Jumbo." The "Jumbo" dynamos were wonderful machines in their day, and a few were running in European electric-light stations until quite lately; but most of them were superseded, soon after their introduction, by faster running central-station dynamos, driven by leather belts instead of being directly coupled to engines.

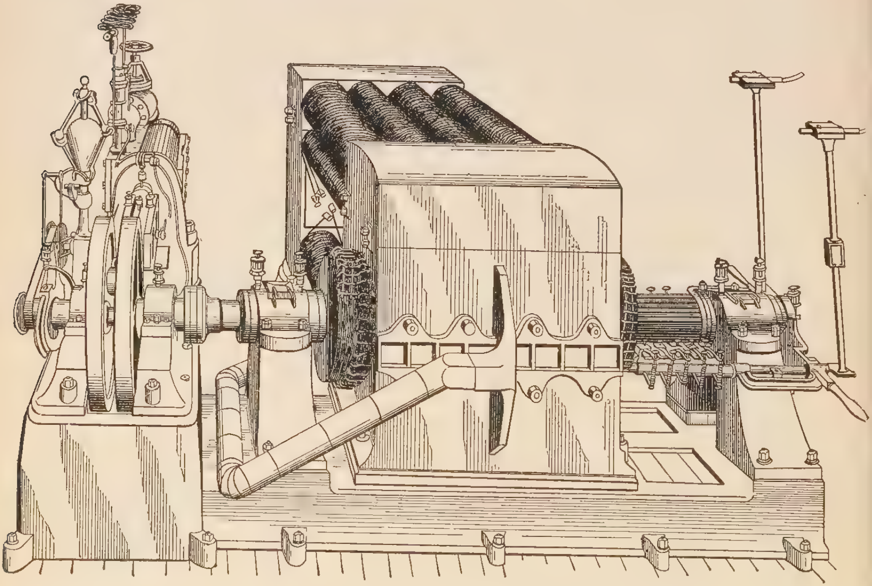

FIG. 197. — Old "Jumbo" Dynamo with its Engine.

**264. The Vertical Station.** — This move to dynamos driven by means of belts caused a change in the arrangements of city central stations, so that several great plants built in New York, Chicago, Philadelphia, and Boston were constructed after the general plan shown in Figure 199. This figure shows a cross section of one of the central stations of the Edison Electric Illuminating Company of New York City. Here high-speed steam engines are located in the basement of the building, so that they may be on a solid foundation, and driving belts run from their fly-wheels to dynamos located upon the floor above. The two floors above the dynamos are occupied by boilers which furnish steam to the engines located in the basement, and by arrangements for handling the ashes which come from the boiler furnaces. Above the boilers is a floor wholly given over to bins for holding coal for the boilers, which is hoisted from the street by an elevator. The top floor is given to repair shops, store-rooms, etc.

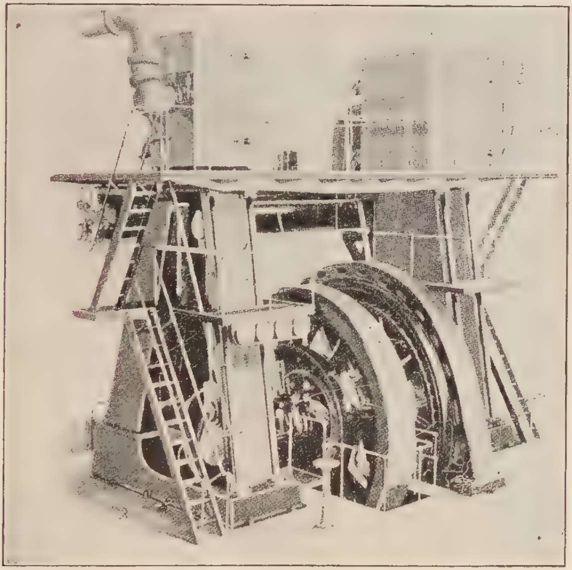

FIG. 198. — Modern Dynamo with its Engine.

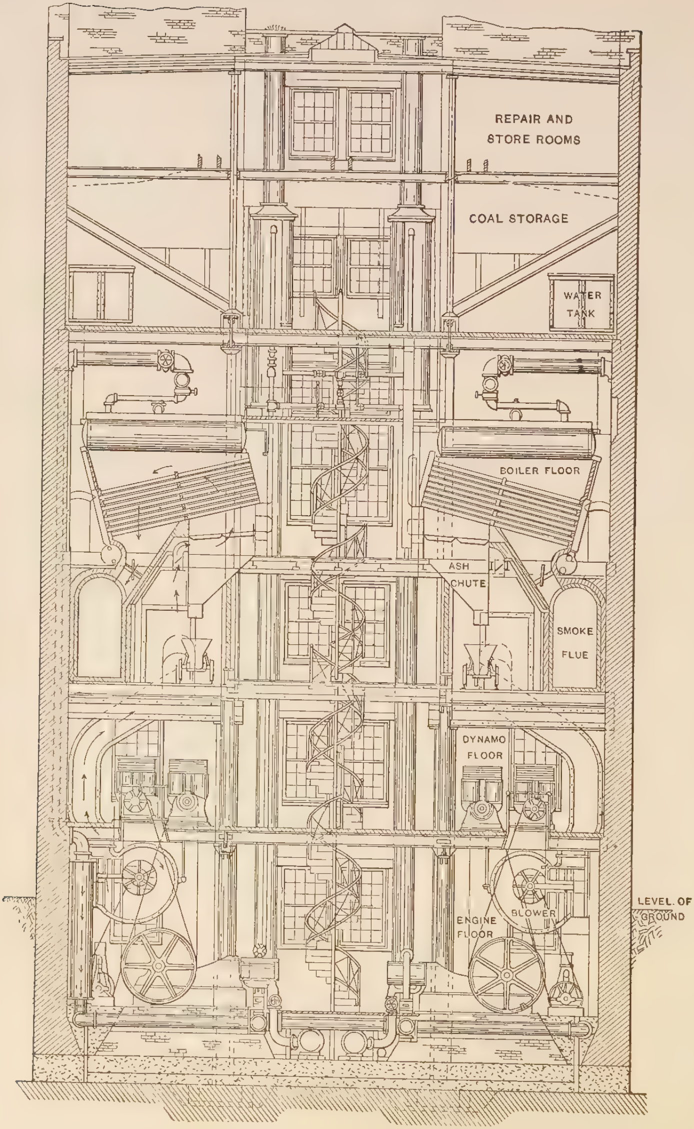

FIG. 199. — Vertical Cross Section of Early Large Station.

This central station fairly represents the type which was used for a number of years in great cities, where, on account of the expense of land, it is desirable to occupy as little ground space as possible. In the great stations which have been built in Chicago, Boston, and New York within the last half decade, the arrangement is still more economical. This will be referred to later.

**265. Plants in Small Cities.** — In the smaller cities, or places where land is not so valuable, it has been usual to place the boilers on the ground floor with the engines, and the dynamos are then placed either upon the same floor or on the floor above.

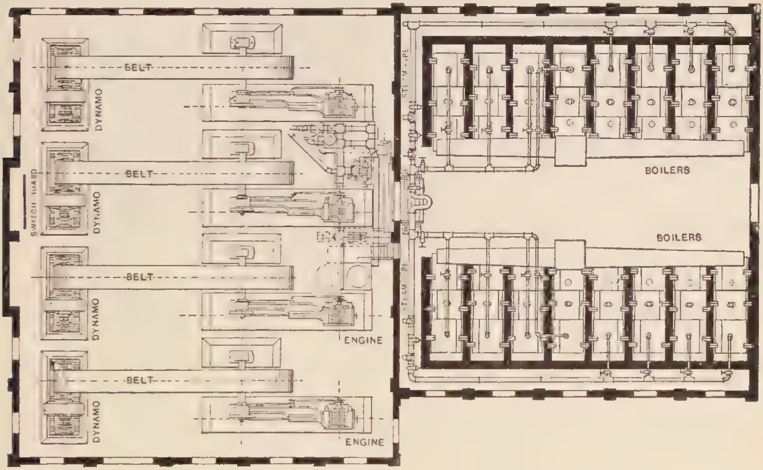

FIG. 200. — Plan of Central Station.

One arrangement of a central station, with the boilers, engines, and dynamos all on the same floor, is well shown in Figure 200. Four engines are shown in this, with a dynamo driven by a belt from each fly-wheel.

A station with boilers and engines on one floor and the dynamos on the floor above is very well shown in Figure 201, which is a cross section of a large plant. The dotted lines in the figure show where an additional engine, with its counter shaft and set of dynamos, may be placed.

These figures are taken from actual plants which are in successful operation, and their counterparts may be seen in a great many cities and towns in this country.

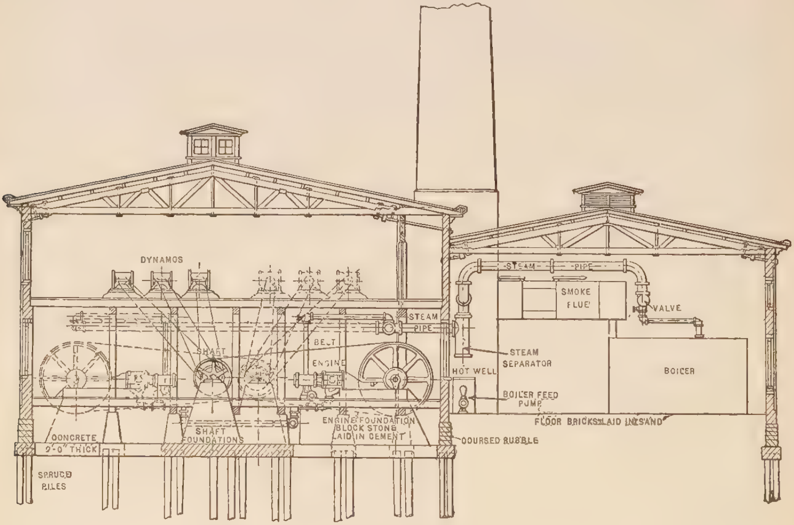

FIG. 201. — Vertical Cross Section of Central Station.

**266. The Niagara Plant.** — After several years, during which small dynamos were used in electric plants, belted to counter shafts or directly to the fly-wheels of engines, the manufacturers of dynamos began again to make dynamos, which, like the "Jumbo" machines, could be directly connected to engines, and such machines are now generally used in central stations. An illustration of a dynamo with its engine is shown in Figure 198. The greatest machines of the kind built until very recently are the great dynamos which are erected in the power house of the Niagara Falls Power Company, at Niagara Falls.

The works of this company constitute the greatest industrial power plant ever constructed. The location of the plant is shown in Figure 202. Taking water from the Niagara River above the falls, a canal built for the power company by the Cataract Construction Company conducts the water about 1500 feet, to where the water-wheels are located. These wheels are placed at the bottom of two enormous wheel pits 179 feet deep, 21 feet wide, and of sufficient length to permit the location of many very powerful turbine water-wheels. The water is conveyed from the canal on the surface of the ground down to the wheels at the bottom of the pit, through great steel tubes or "penstocks," which are $7\frac{1}{2}$ feet in diameter. After the water has passed through the water-wheels, delivering up to them its power, it is carried away through a tunnel a mile and a quarter long, to be discharged into the river below the falls.

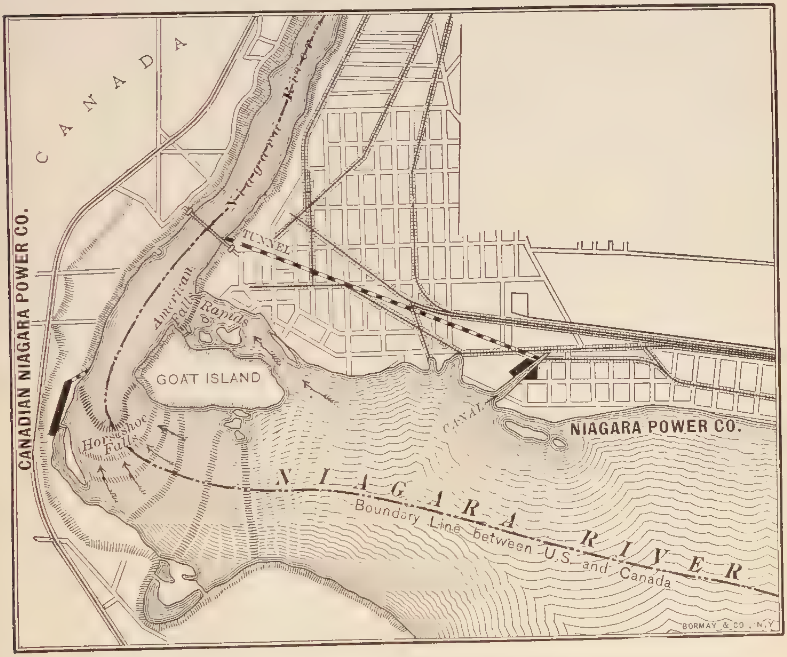

FIG. 202. — Map of Niagara Falls, showing Plant of Niagara Falls Power Company.

The canals and tunnels of the Niagara Falls Power Company have been constructed on such a scale that the amount of water which will pass through them is capable of delivering 125,000 horse power to the water-wheels, and the charter of the company permits it to take more water to about an equal amount. The amount of power represented by this is as much as one-tenth of the power which can be developed by all the water-wheels in the United States, and is greater than the water power of the following great power and manufacturing centres all added together: Lawrence, Lowell, and Holyoke, Mass.; Manchester, N.H.; Lewiston, Me.; Bellows Falls, Vt.; Rochester, Cohoes, Oswego, and Lockport, N.Y.; Paterson, N.J.; Augusta, Ga.; and Minneapolis, Minn.

Even this enormous amount of power which the Niagara Falls Power Company proposes to supply to its customers is very small compared with the power which is contained by all the water in the falls. If all the power represented by the water as it flows through the upper rapids of the Niagara River, over the falls, and through the lower rapids, were utilized, it is estimated that it would make about 7,000,000 horse power, or perhaps three times as much as the power of all the water-wheels in this country, and considerably more than the combined power of all the steam engines and water-wheels which are used in the country.

The Niagara Falls Power Company is unable to take advantage of the total height down which the water flows; but if the power of all the water in the falls were as fully utilized as the power company utilizes the power of the water which passes through its wheels, it is estimated that it would still yield 4,000,000 horse power, or much more than half of all the power now used in this country.

It is therefore to be seen that the great plans of the Niagara Falls Power Company, when fully carried out, are estimated to divert only about one-sixteenth of all the water from the falls, and plenty will remain for the purposes of other power companies, as well as to maintain the grandeur and beauty of the falls unimpaired.

**267. Construction of the Niagara Plant.** — In Figures 203 and 204 are shown two sketch views of the wheel pit and power house of the Niagara Falls Company. The first figure shows a vertical section taken crosswise through the wheel pit and house, and the second shows a vertical section taken lengthwise through a part of the pit and house, and shows the positions of two of the water-wheels and dynamos. In the lower left-hand corner of the latter figure is seen the tailrace tunnel by which the water is discharged into the river. In the figures, *WW* are the water-wheels, each of which is composed of two twin wheels having together the enormous capacity of 5000 horse power, and *PP* are the penstocks. *SS* are great hollow steel shafts no less than thirty-eight inches in diameter. Each shaft conveys the 5000 horse power developed by the water-wheel, to which it is attached, to a great dynamo fastened to its upper end. At *C*, in Figure 203, the canal which brings water to the penstocks is shown, and at *T* is shown the electric travelling crane, capable of lifting fifty tons, which is placed in the power house to be used for placing the machinery in position, and for taking the machinery to pieces if this becomes necessary at any time for the purpose of repairs.

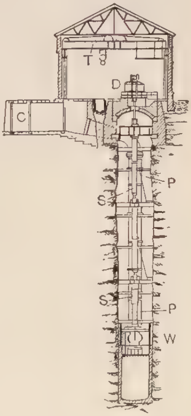

FIG. 203. — Vertical Section across Wheel Pit of Niagara Falls Power Company.

The 5000 horse-power water-wheels, which are over five feet in diameter and revolve at a speed of 250 revolutions per minute, are marvels of engineering and constructive skill, but we cannot stop to consider their details or the remarkable bearings upon which are supported the enormous weights of the revolving parts of dynamo and shaft that are connected to each wheel, and that amount to a total of some forty tons. Suffice it to say that the upward pressure of the water itself is so nicely balanced as to almost exactly overcome this weight when the wheels are running.

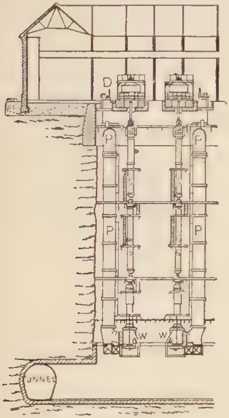

FIG. 204. — Vertical Section along Wheel Pit of Niagara Falls Power Company.

Each dynamo, as a whole, weighs eighty tons and is of the most massive character. These dynamos generate a two-phase alternating current,[1] at 2000 volts pressure, with the quite low frequency of twenty-five periods per second; and the currents are used for operating either motors or lights. As the plant is primarily designed for the transmission of power to factories and mills, it is expected that the greater part of the current will be used in operating motors. Thus far only ten generating units, of 5000 horse power each, have been installed in the electric power house, although much additional water power is now being furnished directly to paper mills.

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[1] Article 246.

A part of the interior of the electric power house is shown in Figure 205. Three of the great dynamos and the end of one of the switchboards are clearly indicated. The frame of the dynamo field magnets, which compose the revolving part, is a ring of forged nickel steel, made by the Bethlehem Steel Company, the great manufacturers of nickel-steel armor plate for the government men-of-war. The pole-pieces, twelve in number, are of soft steel, bolted to the inside of the ring, and wound with rectangular wire. The armature is built up of disks of soft steel, and the windings, of rectangular section, are placed in slots. The armature is stationary and inside of the circumference of the revolving field.

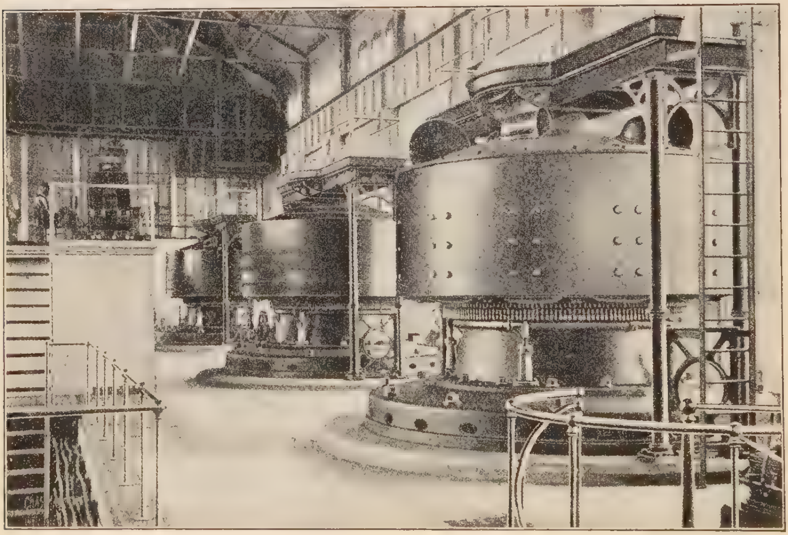

FIG. 205. — Part of Interior of Station of Niagara Falls Power Company.

The first customer to which electric power was delivered when the great dynamos were put into service was the Pittsburg Reduction Company, whose works for the production of aluminum by electrometallurgy were moved from Pittsburg, Pa., to Niagara, in order to take advantage of cheap electric power. Many other manufactories quickly followed, and quite a colony of large mills and factories are gathered about the Niagara electric power house. The Calcium Carbide Works are said to alone take 13,000 horse power from this plant. The current is distributed to these adjacent mills at 2000 volts pressure.

Power is also transmitted to the city of Buffalo, twenty miles away, at a pressure of 22,000 volts. To obtain this pressure, cables are laid from the station switchboard to a transformer[1] room, where the pressure is raised and the system changed by proper transformer connections from two to three phases. The current is then carried out upon the pole line to the city of Buffalo, where it is again reduced in pressure by huge transformers, placed in transformer houses, for distribution through the city. At the present time the street railways, electric lights, and many of the factories and grain elevators of Buffalo are operated by electric power from Niagara Falls. Where direct currents are required, as for the operation of street railways, rotary converters[2] are used. The pole line which supports the transmission feeders is partly in duplicate.

Though the plant at Niagara has now a capacity of only 50,000 horse power, another power house is being erected which will double the output. After a time it is possible that power may be furnished from the Niagara plant, as has been proposed, for the purpose of propelling canal boats on the Erie Canal, and for manufacturing purposes in cities as far from Niagara as Rochester, Syracuse, and Albany. For the transmission of power over these long distances, the pressure at which the current is supplied to the lines may be raised by means of transformers to 50,000 volts or even higher; but before entering the consumers' premises it must be reduced to a safe value, again by means of transformers. Many of the proposals that have been made in the newspapers in regard to the transmission of power from Niagara are manifestly impractical; but many of its possibilities may yet be unappreciated, and it is impossible to foretell the developments that may occur.

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[1] Article 239.

[2] Article 248

The Niagara station will serve to illustrate present practice in building large plants; but it is of interest to add that an electric generating station of 70,000 horse power is just being completed on the banks of New York Harbor, which is intended to supply a portion of the power needs of New York City. Steam engines drive the dynamos in this plant, and the size of the machines, the methods of electrical transmission and distribution, and the purposes of the plant make it even more pretentious than that just described.

**268. Switchboards.** — Before leaving the question of central stations, it is well to examine the common methods of handling dynamos in a plant designed to furnish electricity for lights and power. The current from the dynamos is led to the switchboard by conducting cables of the proper size, which are connected to the main switchboard conductors, called "bus bars," through proper indicating instruments and switches.

In continuous current, low-pressure stations, where shunt-wound dynamos are used, one dynamo terminal is usually connected directly to the proper bus bar without the intervention of a switch, while the other dynamo terminal is connected to its bus bar through a single pole switch. In alternating current stations, where the dynamos furnish a pressure of 1000 volts or more, a double pole switch, to which both cables from the dynamo are connected, is considered essential.

It is usual to operate continuous current dynamos *in parallel*[1] on one set of bus bars, but alternators have been almost always operated on separate circuits in this country, on account of the difficulty of keeping them in step,[2] though the large power stations of recent years are now all operating alternators in parallel. This makes quite a difference in the arrangement of switchboards in the two kinds of stations. In parallel running stations all **Feeders**[3] are connected directly to the main bus bars, but in others the feeder switches are usually arranged so that any feeder may be individually connected to any dynamo as desired. Figure 206 shows the switchboard for a direct current electric lighting plant, having two dynamos and two lamp circuits. The wiring, which is behind the board, is shown by means of dotted lines.

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[1] Articles 103 and 244. [2] Article 244. [3] Article 328.

**269**. **Cutting Machines in and out of Service.** — We will suppose, for an example, a large continuous current station, in which one or two engines with their dynamos have been running all day to supply the demand for current in the daytime, and, as evening approaches, addi-

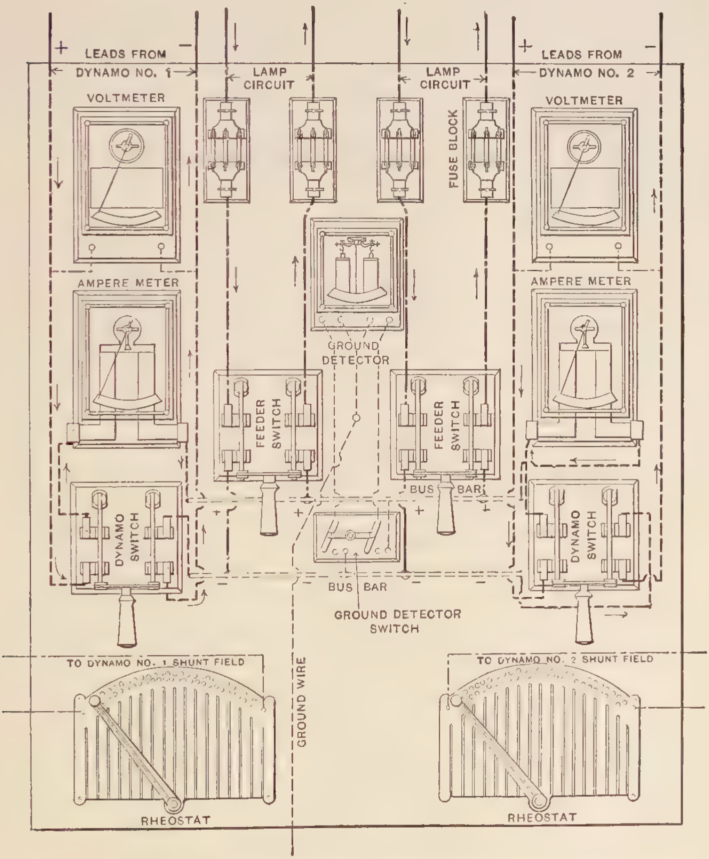

FIG. 206. — Outline of Front of Switchboard arranged to control Two Dynamos and Two Feeders. The conductors used for connecting between the switches, instruments, and other devices, are designed to be on the back of the marble tablet that constitutes the board. These connecting conductors are indicated by dotted lines.

tional engines and dynamos must be put into service to provide for the greater demand for current during the hours of dusk. A short time before additional machines are likely to be needed, one or more engines with their dynamos are made ready for running, and are then started at a slow speed to warm them up.

After a time one of the sets is brought to full speed and the dynamo attendant at the switchboard changes the resistance in the field circuit by means of the dynamo regulator, which is placed on the board, until the lamps mounted on top of the dynamo burn with approximately normal candle power. The dynamo is then ready to be put into circuit whenever it is needed. When this time comes, the switchboard attendant connects the free terminal of the dynamo to a dynamo galvanometer (Figure 207), and moves the dynamo regulator until the galvanometer needle comes to zero. The pressure developed by the fresh dynamo is then exactly equal to the bus-bar pressure. The attendant now closes the dynamo switch, thus putting the machine into circuit, and then moves the regulator until the amperemeter shows that the dynamo is taking its proper proportion of the load.

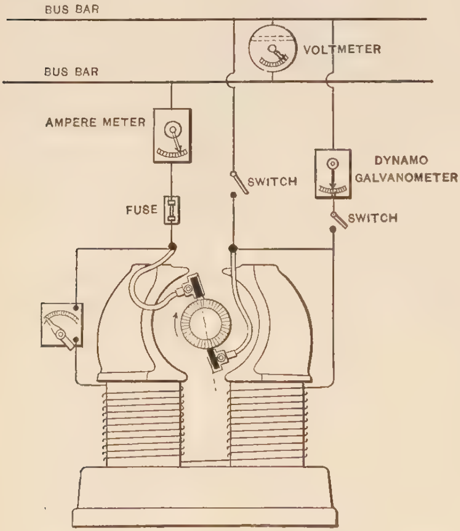

FIG. 207.—Illustration of the Use of a Dynamo Galvanometer.

While this is being done, another generating set is brought to speed and made ready to go into circuit whenever it is required. The operation is repeated until all the dynamo capacity that is required during the period of heavy load is in service. Some cities are subject to sudden periods of darkness caused by clouds or smoke, and at such times it often requires very prompt action on the part of station attendants to get the dynamos into circuit as quickly as they are needed. Instead of a special galvanometer, which is shown in the figure, a voltmeter may be used for comparing the pressure of bus bars and dynamos.

After a period of heavy load is over, the dynamos are withdrawn from the circuit and the engines are shut down. When a dynamo is to be withdrawn from the circuit, its regulator is moved until the amperemeter shows that it carries very little load, and the switch is then opened.

The process of getting extra dynamos into service in an alternating current station is quite similar to the preceding, but after the dynamo is made ready to receive its load, it may not be put in parallel with another machine, but one or more feeders may be transferred to it from another alternator by means of the feeder switches. If, however, the alternators are designed to run in parallel, they are not only brought to the same pressure as the bus bars, but are also brought into synchronism and step. This is done by controlling the speed of the engines a little, and the proper conditions of pressure, synchronism, and step are indicated by an instrument which is connected in the circuit in the same way as the dynamo galvanometer which is shown in Figure 207. This instrument is called a **Synchronizer.**

**Synchronizing**, as it is called, requires a good deal of care; for if the machines are thrown together when they are not running at exactly the same speed and with their pulsations in unison, very bad flickering of the lamps will result. After they are running together properly they tend to keep in step.

**270. Early History of Electric Railways.** — The application of electric motors which probably is most generally known and appreciated is in propelling the electric street cars that are to be found in nearly every city of fair size in this country. When the first large electric railway enterprise was undertaken in the year 1887 in Richmond, Va., prophecies of failure were numerous, and the discouragements met by the promoters of the enterprise were at times sufficient to dishearten almost any one. Before the equipment of that electric railway was undertaken, various experimental electric railways had been laid and operated, and several had been actually constructed for the regular carrying of passengers, but none of them were of such magnitude as the railway at

Richmond, and none served to prove the adaptability of electric motors to the purpose of driving cars as did the equipment which was operated there.

The first electric railway that was really built on a commercial scale was a short line laid in Berlin, Germany, in 1879, by the great firm of Siemens and Halske. In 1883 the first electric railway opened to the public in the United States was operated in the gallery of the Chicago Railway Exposition on a track about 1500 feet long, and of three feet gauge. This electric line caused a great stir in the country and carried many passengers who visited the Exposition. The motor car which ran on the line weighed three tons, and was capable of running at a speed of nine miles an hour. It was therefore quite small compared even with the smallest of electric street cars of to-day, which weigh from eight to twenty-five tons and are capable of running at speeds of eighteen to twenty miles an hour.

Even the striking though modest early attempts at electric railroading made in Berlin and Chicago did little to bring electric cars into general use, though they did serve to stir up the interest of the people. The construction of the early motors, as viewed to-day, was unmechanical and inefficient, so that great improvements were required before the electric cars could replace horse cars or cable cars. Since 1883 the electric car has passed through a period of marked development both in this country and in Europe. From the beginning of 1883 until 1888 several small electric railways were put into operation in this country under the direction of Daft, Van Depoele, Sprague, and others, but until the latter date, by which time Mr. Sprague had made the Richmond road a success, the electric car cannot be said to have proved itself commercially successful.

From 1888 to the present day, electric street railways have grown in number and in favor with remarkable rapidity. So much is this true that the street-car horse has been banished from the streets of nearly all the cities of the country, and the cable railways of the largest cities are also rapidly disappearing.

**271. The Principle of the Electric Railway.** — The principle of the electric railway is very well illustrated by Figure 208. In this figure, *A* is a dynamo, one pole of which is connected, through a switch *S* and fuse blocks $F$, to the street railway track, and the other pole to a wire called the **Trolley Wire**, which is supported over the track. The motor which drives the car is placed underneath the floor, as is shown at $M$ in the figure, and is so geared to the axles that the car is moved along by the revolutions of its armature. In order that current may be supplied to the motor, a movable arm extends above the car, and presses a small wheel against the trolley wire. This arm is called the **Trolley**, and the current is conveyed along it and thence down to the motor. After the current has passed through the motor, it completes its circuit by returning to the dynamo through the rails and earth.

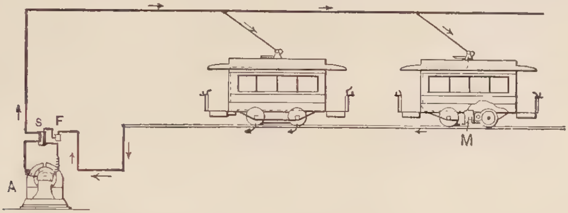

FIG. 208. — Diagram illustrating the Fundamental Features of the Electric Railway.

**272. Railway Motors.** — The motors which are used on electric cars are series wound, and their speed is controlled either by means of a resistance that is placed in circuit with the motor, or by some equivalent device. The motors are of various forms, but those which are now commonly used are completely ironclad, so that the armature is protected from mechanical injury, or from being splashed by water from the track.

Nearly all of the street railway motors that are now used are arranged so that the top and bottom halves of the ironclad fields may be easily separated to enable repairs to be made to the armature or to the field coils. This is an important point to the electric railway owner, because railway service is very hard on electric motors. The machines are exposed to dust and dirt, and are often forced to do more work than that for which they were designed. On account of the cramped space which is to be found under a street car, the motors must be as compact, and at the same time as light, as possible. These conditions combine to make repairs frequent, and very expensive unless the various parts are arranged so that they may be easily accessible. A railway motor is illustrated in Figure 136, with the top part of the frame thrown back so that the armature is exposed.

**273. Motor Trucks.** — The axle bearings of horse cars are usually attached directly to the framework of the car floor, and the same thing is done in cars that are intended to be drawn after electric motor cars as **Trailers** or **Tow Cars.** Such a construction is not sufficiently substantial in electric motor cars, and the axle bearings are mounted on a strong iron framework which is called a **Truck** (Fig. 209). Upon the top frame of this truck is set the car body, while the motors are usually supported from the axles and the truck frame work, as shown in the figure. The figure shows one of the trucks of a long car which has a truck at either end. Short cars have only one truck.

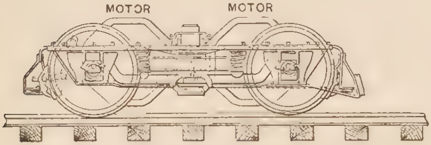

FIG. 209. — Electric Railway Truck supporting a Motor on Each Axle.

It is common practice to place two motors on each ordinary motor car, one being slung on each axle. This is done so as to use as fully as possible all the weight of the car in giving the driving wheels a grip on the rails. When one motor which is geared to only one axle is used, the wheels are likely to slip in bad weather or when the car is on grades, and the speed of the car is retarded, or its progress may even be stopped altogether. Some inventors have arranged gearing so that one motor may drive both axles, but such arrangements have never proved successful when put into the very hard service to which the electric car is subjected. In the usual construction, where the motors are slung from the axles, one end of each motor is supported by means of a spring fastened to a "bolster" or cross timber on the truck.

**274. Railway Pressure.** — In the operation of electric railway motors we have the overhead trolley wire for the outgoing electric conductor, and the rails furnish a path for the returning current. An electric railway motor is, therefore, in an electrical position which is entirely similar to that of an ordinary motor that is arranged to be moved about, and the lead wires of which are slid along the electric mains. Railway motors used in this country are all designed for use with direct currents, and when in service they are connected in parallel across constant pressure circuits. The pressure used is about five hundred volts.

Electric railways often reach out so far from the power station at which the electric current is generated that a lower pressure is not practicable on account of the great amount of copper that would be required to carry the current with a reasonable loss of power. On the other hand, a pressure higher than five or six hundred volts would be unsafe to use on circuits which include bare wires suspended over city streets. The pressure of five hundred volts is sufficient to give a severe shock, but it is not ordinarily dangerous to human life, as has been proved by long experience, though horses and some other animals which are more sensitive to electric shocks than human beings have been killed by contact with electric railway wires.

As the lengths of electric railways have been increased, it has sometimes been found necessary to use high pressure alternating currents for transmitting the power from the central generating station. The pressure is then reduced by stationary transformers located at sub-stations along the line, where the current is also rectified by means of rotary converters.[1]

**275. Wiring Requirements.** — The trolley wire of an electric railway commonly consists of a conductor of hard drawn copper of from No. 0 to 000 B. & S. gauge in size, which is suspended from **Span Wires** or brackets supported on poles. When the distances over which current must be carried are so great that a No. 000 wire is of insufficient conducting capacity, feeders may be run from the power station to various feeding points, where they are connected to the trolley wire.

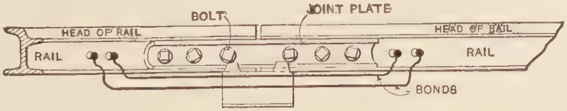

FIG. 210. — Rail Joint with Joint Plate and Bond Wires.

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[1] Article 248.

The conducting capacity of the track must also be carefully looked after, even in the shortest lines. The rails of which the track is composed are about thirty feet long, and their ends are mechanically connected by means of joint plates or **Fish Plates** and bolts. On account of the scale which is found on the rails and fish plates, the joints do not conduct electricity satisfactorily, and it is necessary to join the rails electrically as well as mechanically. For this purpose what are called **Bonds** are used. A bond is a short piece of copper wire, the ends of which are riveted into the adjoining ends of two rails, and it thus serves to make a good electrical connection between them (Fig. 210). Sometimes a copper or an iron wire is placed in the ground between the rails, and each rail is connected to it by means of a bond (Fig. 211), and the electrical connection between the rails is made by means of this continuous wire.

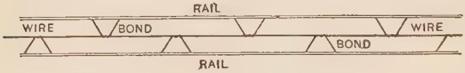

FIG. 211. — Electric Railway Track reinforced by Continuous Wire.

**276. Heavy Railway Service.** — The electric motor has also found a place in railway service which is much heavier than that of the ordinary surface street railways.

After working its way into favor on street railways, it came rapidly into use upon light suburban railways, and is now looked upon as an essential feature of any new system of city rapid transit. Possibly one of the most striking examples of the use of electric motors upon rapid transit systems is on one of the underground railroads in the city of London, where electric locomotives are used to draw the trains, to the great improvement of the atmosphere and cleanliness of the tunnels. The equipment of this railway was followed by the operation of an elevated railway in Liverpool, England, and the Intramural Railway at the World's Fair, both of which were started in the spring of 1893. In this country there are now in operation several great systems of elevated and city rapid transit electric railways, and others are planned in which electric motors are expected to play a prominent part. The list of those planned includes the great underground railroad system which is being built to give the inhabitants of New York City a satisfactory means of transportation from their business places down town to homes located a number of miles away to the north.

Even this does not set the limit to the field of the electric motor when applied to railway purposes. The heavy passenger trains of the Baltimore and Ohio Railroad are drawn by means of electric motors through the great tunnel under the city of Baltimore. One of the type of electric locomotives used for this purpose is illustrated in Figure 212. Following this example, several other steam roads have been equipped with electricity for short distances, and the results have proved satisfactory. It is now generally believed that the electric car will invade many parts of the field which has heretofore been exclusively occupied by the steam locomotive, and that, in some kinds of service, the electric motor will as completely displace steam locomotives, as it has already displaced horse cars and cable cars for surface transportation in the smaller cities. Experiments have even been made with a view to placing electric locomotives in service upon main trunk railway lines; and the superintendent of an important English railway, it is said, believes he could quickly change his whole system from one using steam locomotives to one using electric locomotives, if the officers of the road so directed. Be this as it may, the fact is plain that the electric motor has made a wonderful record for itself when used upon electric railways in the past and that its record will be much more remarkable in the future.

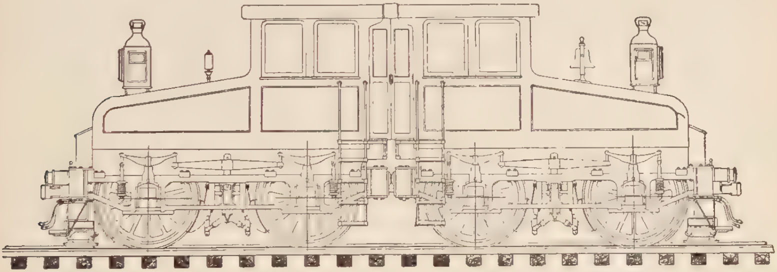

FIG. 212.— Electric Locomotive for hauling Heavy Trains.

**277. Station Management and Loads.** — The question of getting the greatest possible amount of work out of his machinery, and at the same time of expending the smallest practicable amount of money for its safe operation, is one which weighs continually on the mind of the manager of every great electric plant. It is this which leads him to watch all expenditures and keep an accurate account of all the supplies used in his station. The accounts show him the cost of fuel, oil, water, labor, and other items, for every 1000 watts generated for an hour by the dynamos. By comparison of these records month by month, and also the records of other plants of similar size, it is possible to tell whether every economy is practised which will not cause oppression to the employees or injury to the plant.

The record of the output of a station may be made by the switchboard attendant, who, every quarter or half hour, enters the readings of the feeder amperemeters and the voltmeters in a large book which is properly ruled. Sometimes the record is made by integrating wattmeters[1] and other automatic instruments. Figure 213, for instance, is a reproduction of the card taken from a **Recording Voltmeter** which is used in a large central station for electric lighting. The card shows the continuous record of the pressure which was maintained at the centres of distribution during twenty-four hours. The distance between two successive radial lines represents fifteen minutes, and the distance along the radial lines included between any two adjacent circles represents two volts. Recording amperemeters are not as commonly used as are recording voltmeters, as the voltmeter record is a check upon the care with which the pressure is kept constant, while there is no particular need of keeping an extremely exact record of the current.

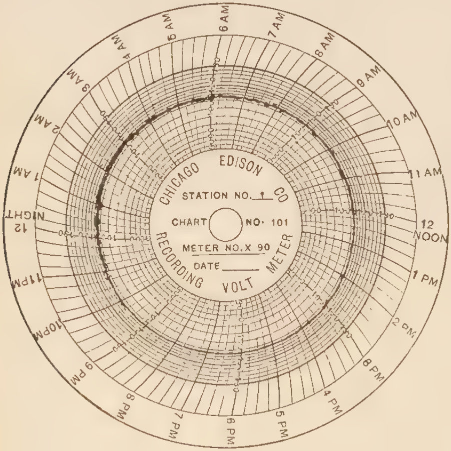

FIG. 213. — Record of Bristol Recording Voltmeter.

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[1] Article 188.

Figure 214 shows the current sent out from a certain electric light station during twenty-four hours. The hours of the day and night are laid off on the horizontal line, and the current at any hour is equal to the length of the corresponding vertical line which is included between the horizontal line and the irregular line. This shows very plainly the effect of the dark hours of the afternoon in causing a great increase in the demand for light. A curve of this character, which shows the current sent out from a station at every moment throughout the day, is called a **Load Curve.**

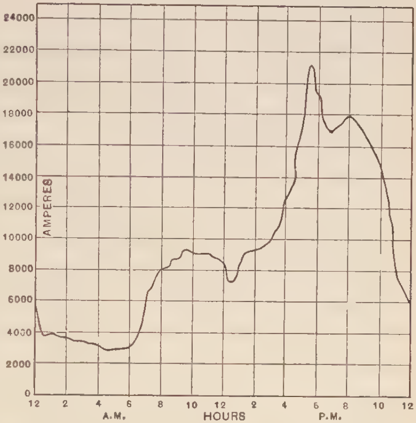

FIG. 214. — Load Curve of Electric Light Station.

The total amount of current which is required by the customers of an electric light plant changes from hour to hour with comparative slowness, as is shown by Figure 214, and such an amount of machinery can be kept running at all times as will supply the load most economically. A very different condition exists in the power house which supplies current to electric street cars. Figure 215 shows the amount of current sent out during one hour from an electric railway power house, the record being laid out in the same way as that of Figure 214. This figure shows the wonderful range and rapidity of the changes in the current supplied by the station. Since compound wound dynamos which keep the pressure fairly constant are used in such stations, the variations of the current cause similar variations of the load on the dynamos and engines. Every effort has been made to reduce the range of these changes which cause shocks to the machinery and so are likely to finally result in injury or breakdown, and which also make it impossible to keep the machinery sufficiently well loaded so that it may be operated with the greatest economy.

One method which is used with a view to decreasing the great changes in the load on railway stations calls for the use of a storage battery. This battery has its positive terminal connected directly to the positive bus bar and its negative terminal to the negative bus bar; then when a great demand for current is made by the cars, part of it is supplied by the battery, and the dynamos and engines are relieved to some extent. When the current required by the cars is small, the battery takes current from the dynamos, by which means it is kept charged; and thus the variations of the load on the engines are made much smaller than they would be without the battery. Storage batteries are also used in a few large American and various foreign electric light stations to aid in supplying the current during the period of greatest load, and the batteries are then recharged during the period of light load. They cannot be very satisfactorily used in small plants because of their great expense.

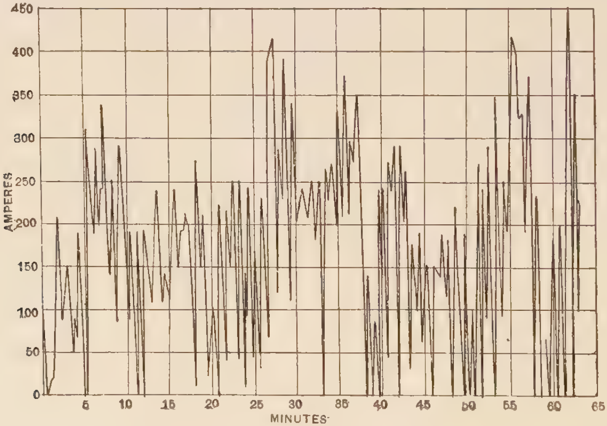

Fig. 215. — Load Curve taken for One Hour in Electric Railway Plant.

**278. Electric Car Controlling.** — The detail improvements which have had the greatest effect upon the loads of electric railway power stations lie in the street-car motors and the manner in which they are controlled. The earlier motors which were put upon street cars were wired up so that the two machines were put permanently in parallel, and they were then controlled by means of resistances put in series with them. Some cars are still controlled in this manner. When the car is to be started, a controller lever is moved so that it connects the two motors to the circuit in parallel with each other and in series with a resistance. To make the cars run faster, the resistance is gradually cut out of the circuit, and finally a certain portion of the series field coils of the motors may be cut out also, if a particularly high speed is desired.

Another way of controlling the speed of street cars is by what is called the "commutated field" method. In this case the fields of the motors are wound in separate divisions, usually three in number, and the speed of the motor is controlled by connecting the field coils of each motor in different combinations. When a car is to be started, the switch handle is moved to a position which causes the three field coils on each motor to be connected in series with the armature. To cause the car to run faster, the lever is moved from point to point, commutating the fields into various arrangements, until on the seventh and last notch the individual field coils are in parallel. It is of some interest to know that this system was developed by Sprague while working on the historic line in Richmond. These methods of motor control are also used to some extent for hoisting and other variable speed series-wound motors.

**279. Series-parallel Control.** — Both of the earlier forms of controllers served very well as far as the handling of cars is concerned, but the use of resistances in the manner described causes a great waste of power, and consequently the cars require a great deal of current in starting. This in turn has an effect in increasing the suddenness and magnitude of the changes of load at the power station. The need for a more efficient controller which would waste less power and allow the cars to start with less current became so pressing that various devices were designed to meet the want. All of these were reduced to some form of "series-parallel" controller.

The pull or **Torque** with which a series-wound motor tends to start depends only upon the current flowing through it. If two motors are connected in parallel, and enough current is passed through them to start a street car, the total amount of current may be as much as eighty amperes. The starting effort in this case is caused by *forty amperes flowing through each motor.* Now, if the same two motors are connected in series with each other, and a current of forty amperes is permitted to flow through them, each will exert the same starting effort as before, and the car *will start with the expenditure of only half the current.* Having started the car, the motors must be connected in parallel in order that they may run at a reasonably high speed, because when the motors are in series the total pressure of 500 volts is divided between them, and each, therefore, gets only about 250 volts. The speed of a motor depends directly upon the pressure at its armature terminals, and therefore, when connected in series, the motors will run at only half speed.

**280. Starting Current Curves.** — The actual process of controlling a car by the series-parallel method consists of starting the car with the motors in series with each other and a resistance, cutting the resistance out of circuit, and then by a series of commutations indicated in Figure 216, putting the motors in parallel with each other, and in series with the resistance. This resistance is finally cut out of the circuit to make the car run at a high speed.

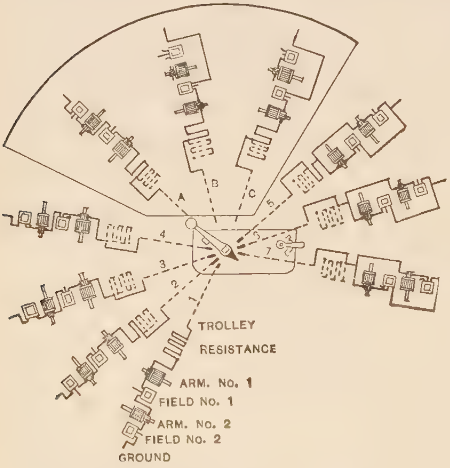

FIG. 216. — Diagrammatic Illustration of the Operation of a "Series-parallel Controller."

The comparative efficiency of operating cars with motors equipped with rheostat and with series-parallel controllers is illustrated in Figure 217. The time after current is admitted to the motors is laid off on the horizontal line, and the distance from the horizontal to the wavy lines at any point shows the amount of current flowing through the motors at that instant. The upper wavy line shows the current consumed when a certain pair of motors were controlled by a rheostat, and the lower wavy line shows the current consumed when the same motors were controlled in the series-parallel fashion. During the first ten seconds the rheostat control required twice as much current on the average as did the series-parallel control, and during the first eighteen seconds the rheostat required one-half more current.

A similar figure might also be drawn to illustrate the difference between the amounts of current used by a careful motorman in starting his car and by a careless man. The former always moves his controller lever from point to point with care, and permits the motors to gather speed before passing from one point to a higher one. By neglecting this precaution a considerably larger current may be used than is necessary. Some steam railroads pay a bonus to the engine driver who succeeds in making his runs each month with the least coal, and it would be a paying investment for many electric railroads to pay a bonus to their motormen who succeed in making the runs with the least current.

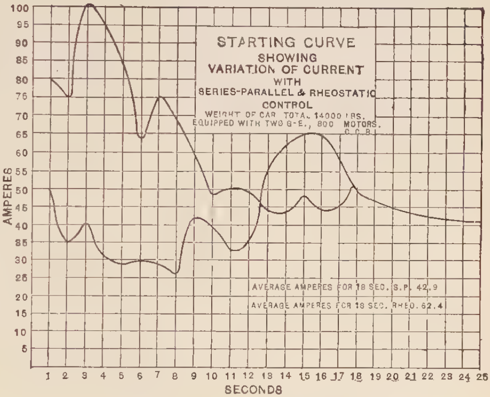

FIG. 217. — Illustration of the Saving effected by the Use of the "Series-parallel Controller."

**281. A Few of the Uses of Stationary Electric Motors.** — During the past decade electric motors have come to be almost a necessity to people who live in small cities, and use small amounts of power. The wonderful way in which electric motors have come into general use is very striking. The number used in Chicago in the year 1889 was very small, while in 1894 motors to more than four thousand horse-power capacity were supplied with current from the distributing system of the Edison Illuminating Company of that city. The increase since then has been equally rapid. In addition to these motors, many more are supplied with current from either central or isolated plants. Chicago is not at all exceptional in the number of electric motors which its inhabitants use, for large numbers are also used in New York, Boston, Philadelphia, and other large cities. In fact, electric motors are as necessary to the small users of power who live in American cities, large or small, as gas engines are to the citizens of Paris, and they have also become household necessities in many places.

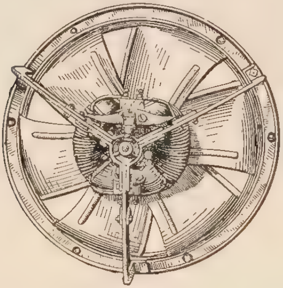

FIG. 218. — Large Fan driven by Electric Motor.

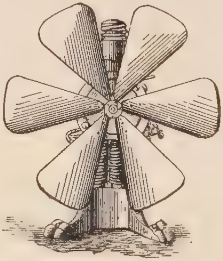

FIG. 219. — Small Fan Motor and Fan.

The use of electric motors in small shops and for household purposes is by no means limited to the large cities; but in all places where a power supply is at hand throughout the day, the motors are found in many kinds of service. One of their commonest uses is to drive small fans for stirring up the air in a room in the hot summer days. Such **Fan Motors** are common in offices, theatres, and public places. An interesting use

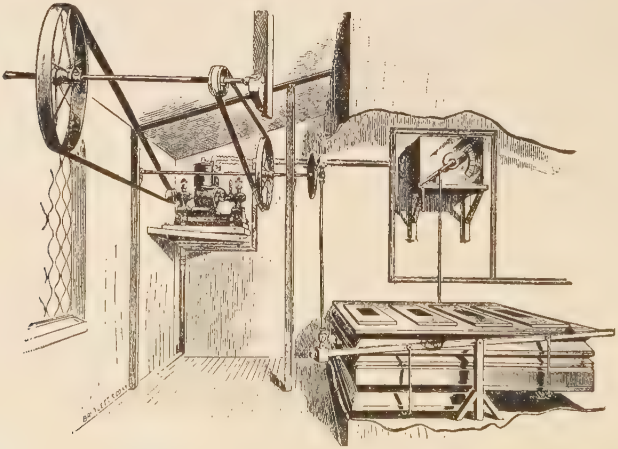

FIG. 220. — Great Organ Bellows driven by Electric Motor.

of fan motors is made on the electrically lighted trains of the Pennsylvania and other railroads, the dining cars of which are made very comfortable on hot summer evenings by several fan motors, which take current from the electric light circuits.

An example of motors used with an isolated plant is to be seen in the great plant of the Auditorium Hotel and Theatre in Chicago, where motors having a combined capacity of several hundred horse power are in daily use. These motors are used to drive ventilating fans and small blowers, as shown in Figures 218 and 219, to run coal and ash hoisters, meat choppers and coffee grinders for the kitchen, machinists' tools for the repair shop, bellows for the great organ (Fig. 220), to drive a small dynamo which furnishes current for the hotel bells, and for other purposes. Some of the dynamos of this plant are required to run all day and all

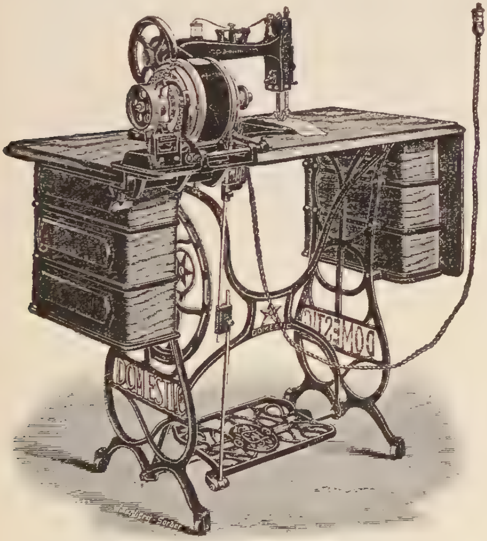

FIG. 221.—Sewing Machine with Electric Motor.

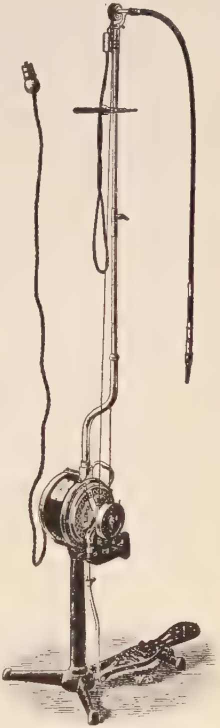

FIG. 222.—Dentist's Lathe with Electric Motor.

night, so that a supply of current is always on hand by means of which the motors may be operated.

The uses to which electric motors may be put are almost endless, but a few of the common applications are illustrated in the figures of this article. In Figures 221 and 222 are shown a sewing machine and a dentist's lathe, each with a motor connected to it. Figure 223 shows how a pump may be driven by an electric motor. An electric motor driving a contractor's hoist, which is used in the construction of a large building, is shown in Figure 224, and a small electric mining hoist is shown in Figure 225.

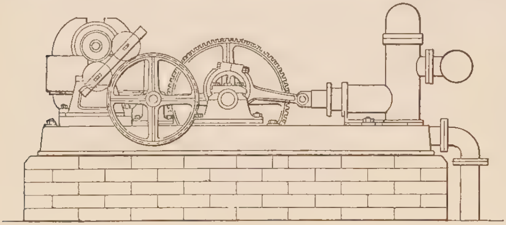

FIG. 223. — Electric Pump.

This list of illustrations might be extended to an indefinite extent without exhausting the various purposes for which electric motors may be used, and for which, indeed, they are used in great numbers.

**282. Counter Electric Pressure of a Motor.** — It has already been explained that the cutting of lines of magnetic force by a conductor always sets up an electromotive force in the conductor.[1] This occurs in a dynamo armature when the conductors are caused, by the rotating of the armature, to move across the lines of force of the magnetic field in front of the pole pieces. And the electrical pressure thus produced in the dynamo armature causes a current to flow when the circuit is complete. A similar pressure is also set up in the armature conductors of an electric motor, when they are caused to cut the lines of force of the magnetic field by the rotation of the armature; but *this pressure produced in the motor armature is opposed to the current which causes the rotation of the armature*, and it is therefore called a **Counter Electric Pressure**, or **Counter Electromotive Force.**[2]

When a motor armature gathers speed after it is started, the counter electric pressure becomes greater and greater as the speed grows faster and faster, because more lines of force are cut in each second; and the

[1] Article 195.

[2] Article 207.

current flowing through the armature meets the increased opposition of this counter electric pressure. The speed and counter pressure of the armature increase until the armature has reached a speed where the counter electric pressure is nearly equal to the pressure of the circuit to which the motor is connected. Then the speed and current become constant, and remain so as long as the load on the motor and the circuit pressure remain unchanged.

**283. Effect of Armature Resistance.** — The counter pressure of the motor armature can never become equal to the pressure of the circuit, because a certain pressure is required to push the current through the resistance of the armature conductors. In shunt-wound motors the sum of this with the counter pressure is equal to the circuit pressure.

FIG. 224. — Hoisting Derrick with Electric Motor.

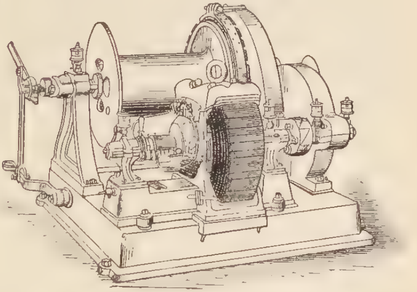

FIG. 225. — Small Electric Mining Hoist.

When the current flowing through the motor is multiplied by the circuit pressure, the product gives the amount of power (in watts) which is given to the motor by the circuit.

The product of the armature current by the pressure which is required to push the current through the armature conductors of the motor gives the watts wasted in the heating of the armature conductors. This is called the $C^2R$ loss of the armature, and should be quite small, in order that the motor may be reasonably efficient and regulate well.

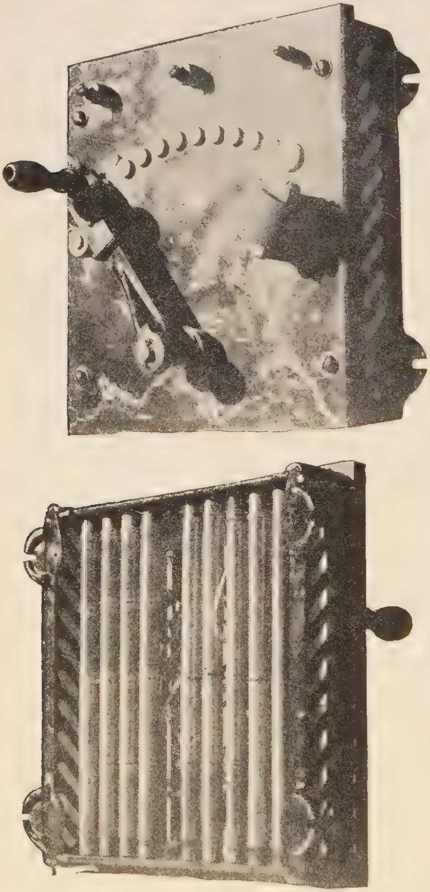

FIG. 225*a*. — Exterior and Interior of Motor Starting Box.

The product of the armature current with the counter electric pressure is equal to the power that is exerted in causing the armature to rotate; and the more nearly the counter pressure approaches the circuit pressure when the motor is running, the better is the efficiency of the motor and the better will it regulate. We sometimes hear of an attempt to build an improved motor which produces no counter electromotive force; but all such attempts are doomed to failure, *since the success of the motor depends upon its producing the counter pressure.*

**284. Starting Box or Rheostat.** — As the resistance of the armature of an electric motor is usually quite small, for the reasons presented in Article 283, some special means must be provided for avoiding too great a rush of current, when a motor is to be started by connecting it to a circuit.

The resistance of the armature of a ten horse power motor, which is designed to be operated in connection with a 220-volt circuit, may be about three-tenths of an ohm, or even less. The current that such an armature may be expected to carry at full load is nearly 40 amperes. Now, if this armature is connected across the 220-volt circuit while it is at rest, the only opposition which the current meets is that caused by the resistance, since no counter electric pressure is developed while the armature is standing still; and the current that instantly tends to flow through the armature is, in accordance with Ohm's Law, 220/.3 = 733 + amperes, — a sufficient current to overheat and ruin the armature, unless the circuit is instantly broken.

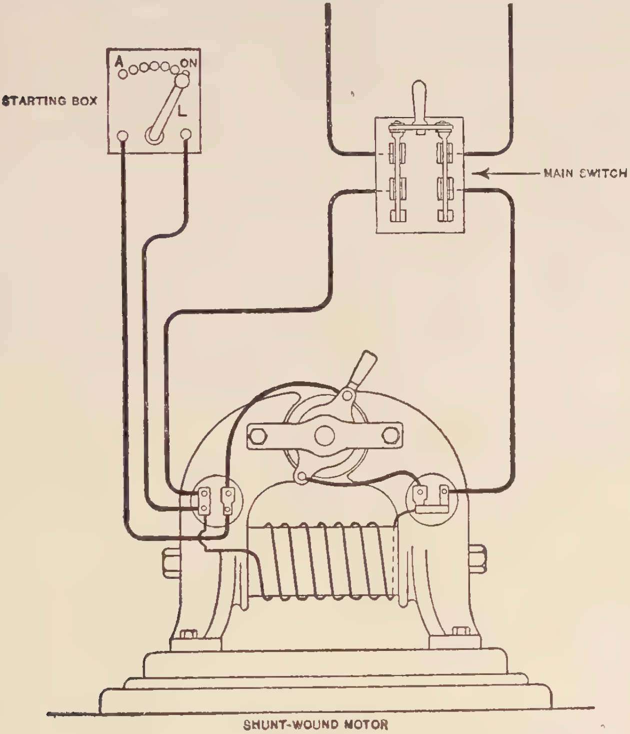

FIG. 225*b*. — Diagram of Plain Starting Box connected in Circuit with Shunt-wound Motor.

It is necessary, therefore, to insert a certain amount of resistance in series with the armature, when the motor is to be started, so that the current may be choked back until the rotation of the armature has reached a speed which causes it to produce sufficient counter pressure to prevent an excessive rush of current through the windings. A resistance box made up for this purpose is called a **Starting Box** or **Starting Rheostat.** A usual form is illustrated in Figure 225 *a*. It consists of a box full of iron wire resistance coils, wound on asbestos tubes or some similar incombustible material. These are all connected in series, and one end of the series is connected to a binding post. The resistance coils are connected at intervals to buttons that are shown on the front of the box. The lever arm shown in the figure is connected to a binding post by a short wire behind the box cover.

When the starting box is connected in the circuit with a shunt-wound motor in accordance with the illustration (Fig. 225 *b*), the motor may be safely started by the following procedure. When the main switch is closed, the current flows through the field winding and sets up the field magnetism. The handle of the box lever *L* is then moved slowly toward the right, from button to button. When the lever contact is on the button marked *a*, all the resistance of the starting box is connected in series with the motor armature. As the lever contact moves toward the right, the resistance included in the circuit is gradually reduced; and when the lever contact stands on the button marked "on," all of the resistance has been cut out, and the motor armature is connected directly to the circuit. In the meantime the armature has been given an opportunity to come up to its regular speed, so that the counter electromotive force is amply sufficient to prevent the current from becoming excessive.

The resistance of the coils in the starting box must be sufficient to prevent much more than the normal current of full load from flowing through the armature when it is stationary. In the case of the ten horse power motor referred to above, the starting box should contain not less than 4 or 5 ohms, and the rheostat coils should be capable of carrying the full load current for several minutes without becoming dangerously hot.

**285. Automatic Release.** — Most starting boxes nowadays are fitted with an automatic arrangement that allows the contact lever to return to its "off" position in case the main switch is opened or the current supply fails for any reason. This is very desirable, since it disconnects the motor from the circuit, and prevents it from being injured in case the current supply is renewed while the armature is at rest. This construction also makes it impossible, after the motor is started, to leave the contact lever permanently in a mid-position, which might result in dangerously overheating the resistance coils, and such starting boxes are recommended in the rules of the Underwriters, and are required for many locations. Figure 225 *c* shows the circuit connections of a box of this character.

Some starting boxes also have an overload cut-off arrangement, which stops the motor if it is overloaded.

**286. Starting and Stopping Motors.** — When a shunt-wound motor is to be started, the main switch is first closed. The contact lever of the starting box is moved to the first button, the field magnets become excited, and the motor armature begins to move. The contact lever is then slowly moved to the "on" button, while the motor gathers speed. Care must be taken to avoid cutting the resistance of the starting box out of the circuit too rapidly, in order that the starting current may not be too great; but the lever must not be permitted to stand more than a short time (perhaps a half minute) on any one button, because the resistance coils are intended to carry a large current for only a short time.

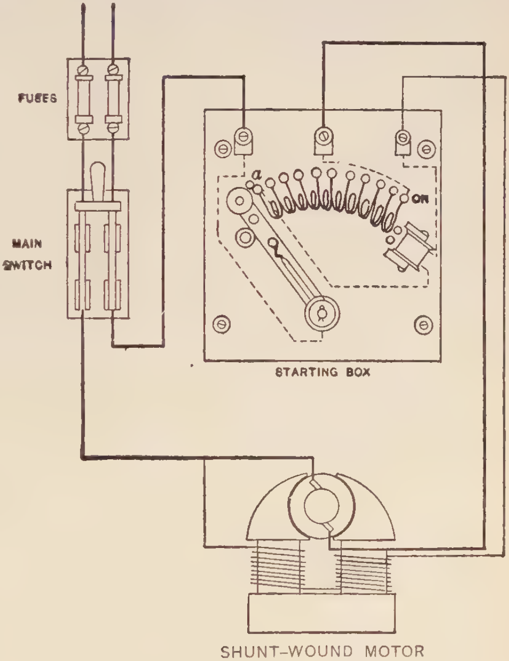

FIG. 225 *c*. — Diagram of Automatic Starting Box connected in Circuit with Shunt-wound Motor.

In stopping a motor, the main switch should be opened. After the armature has nearly stopped, the contact lever of an automatic starting box returns to its "off" position. If the starting box is not automatic, the lever must be returned by hand.

**287. Reversing the Direction of Rotation.** — To reverse the direction of the rotation of a motor armature, it is necessary to reverse the relative direction in which the current in the conductors flows through the magnetic field. Consequently, either the current in the armature coils must have its direction reversed while the field magnets retain their original polarity, or else the polarity of the field magnets must be reversed without changing the direction of the current in the armature. A simple exchange of the positive and negative terminal connections of the main circuit to the motor has no effect on the direction of the rotation of the armature, since the polarity of the fields is reversed by this exchange at the same time that the direction of the current in the armature coils is reversed. This exchange, therefore, does not change the *relative* conditions. Consequently, *to effect a reversal of rotation, change either the direction of the current in the field coils, or the direction of the current in the armature, but not both.* Reversing the direction of the current in the armature coils is the commoner method of effecting the reversal of rotation. If a motor is to be often reversed, as in elevator work, it is usual to provide it with relatively powerful field magnets, so that the

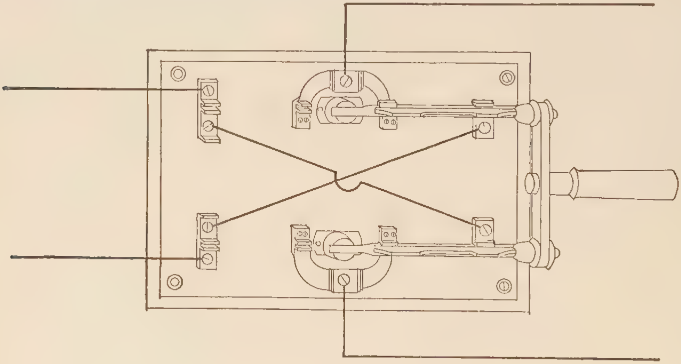

FIG. 225 *d*. — Reversing Switch.

positions of the brushes on the commutator need not be changed during its ordinary operation. Figure 225*d* illustrates a form of reversing switch which is often used with electric motors.

**288. Motors and Manufactories.** — A place in which electric motors are coming to be very much appreciated and widely used is in large manufactories. The ordinary method of carrying power through shops by means of great belts and heavy shafts is very wasteful of power. The attached table, taken from one in Professor Flather's book on power measurements, shows the amount of power lost in belting and shafting, and the amount actually delivered where it is required for use, for every hundred horse power developed by the engine. The table shows that *from one-fourth to four-fifths of the power of the engines is actually wasted in simply making shafting revolve, and causing the belts and gears to run.*

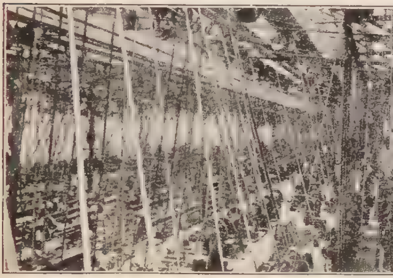

FIG. 226. — Machine Shop in which the Machinery is driven by Belts.

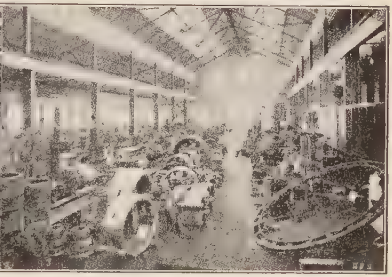

FIG. 227. — Machine Shop in which the Machinery is driven by Electric Motors.

| Name of Works | Power lost, Per Cent | Power used, Per Cent |
|---|---|---|
| Union Iron Works | 23 | 77 |
| Frontier Iron and Brass Works | 32 | 68 |
| Baldwin Locomotive Works | 80 | 20 |
| Wm. Sellers and Company | 40 | 60 |
| Pond Machine Tool Company | 41 | 59 |
| Bridgeport Forge Company | 50 | 50 |
| Yale and Towne Company | 49 | 51 |
| Ferracute Machine Company | 31 | 69 |

Shafts and belts are a great nuisance in shops, and any convenient arrangement which can take their place would be very useful, even if it did not save power. *A convenient arrangement which takes their place and at the same time saves much power is of the greatest service.* It is in this place that the electric motor shows one of its finest characteristics. In Figure 226 is shown a large machine shop in which the power is distributed by shafts and belts, which give the shop somewhat the appearance of a forest, while in Figure 227 is shown a similar shop after the lathes, planers, and other machines are arranged to be driven by electric motors. The motors are close to the machines, and the electric wires leading to them are put out of the way so that the shop presents a much improved appearance.

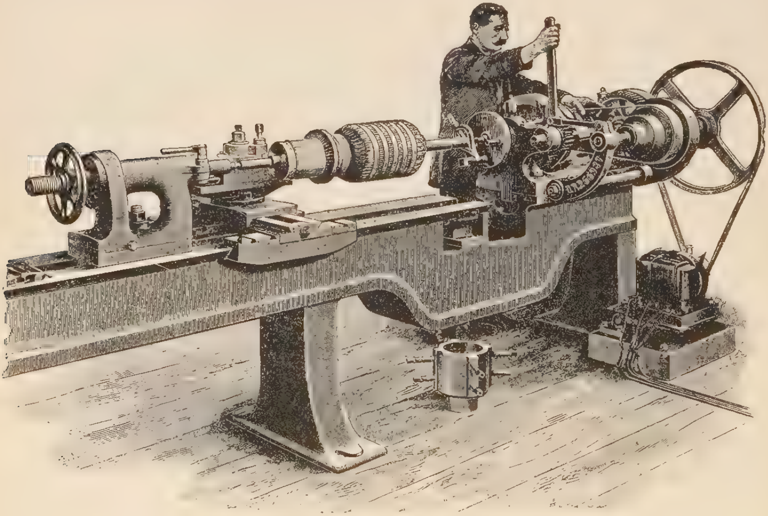

FIG. 228. — Machinist's Lathe arranged to be driven by Electric Motor.

The improvement is as great in fact as in appearance, because the removal of shafting and belts removes a great source of danger and inconvenience, and electrical distribution of the power is much less wasteful than distribution by shafts and belts. A properly arranged electrical distribution of power also makes it possible to place every lathe, planer, or other machine at the position in the shop where it may be used most conveniently; and the speed of each machine may be adjusted by the turn of a hand to best suit any work that is being done. These conditions enable an electrically driven factory to execute more work than a similar establishment where belt driving is used. The advantages which may be gained by using electricity instead of belts and shafts is worth a great many dollars to the owners of the shops; and many shops have, therefore, been arranged for electrical transmission, while many more are being so arranged. Figure 228 shows the way in which a motor may be applied to drive a lathe or drill or other machine, while Figure 229 shows a large travelling crane which is driven by electric motors. Such cranes are used in nearly all large machine shops.

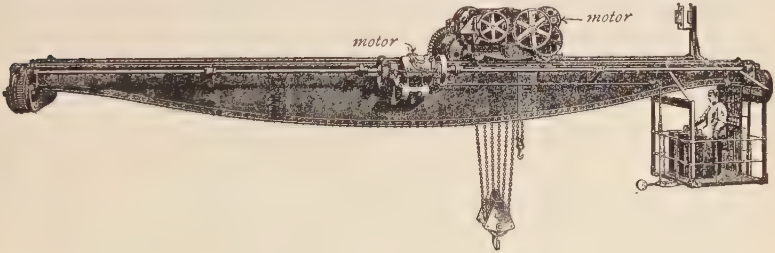

FIG. 229. — Travelling Crane with Electric Motors.

The arrangement of electric motors which will give the best results in any shop depends upon a great many things, and can only be arrived at by good judgment. The ideal method would be to have one or more motors built as a part of every machine in the establishment, but this would make the machinery too costly, and consequently cannot be carried out, though it would probably be the most convenient and satisfactory arrangement which it is possible to make. The next best arrangement, and the one which is usually adopted, is to have all large machines which require considerable power furnished with separate motors. These may be built into the machines, thus doing away with all unnecessary belting or gearing, or they may be directly belted to the usual driving pulleys of the machines. Smaller machinery may be arranged in groups of two to six machines with a motor to supply power to the machines of each group through a light shaft.

The amount of power required to drive different classes of machinery is, as a general rule, quite uncertain.

The width of the belt which is commonly used on a machine is some indication of the power required, as it may be assumed that a single leather belt when running at the ordinary speed used in shops will satisfactorily drive from one to two horse power per inch of width. A double belt will generally drive about twice as much as a single one. An exact estimate of the power used by any machine cannot be made from the size of its belt, however, since the driving power of a belt depends, amongst other conditions, directly upon its speed, and even at ordinary speeds it may transmit very much more power than the rule given above would indicate, though its operation would be unsatisfactory.

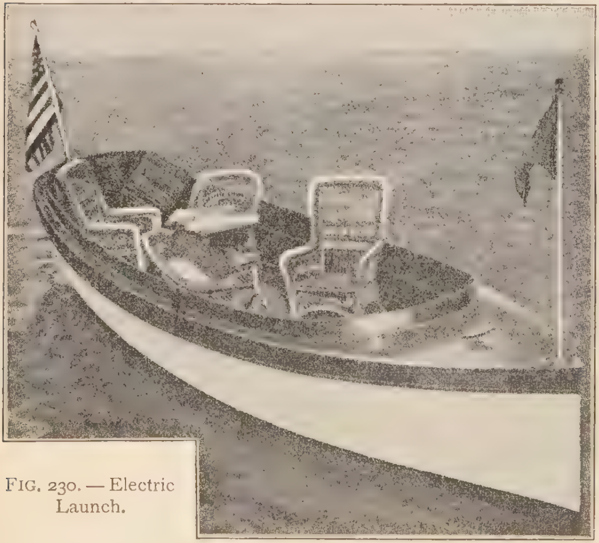

FIG. 230. — Electric Launch.

**289. Electric Launches and Automobiles.** — Before leaving this subject, the use of electricity upon boats and automobiles must be touched upon. Figure 230 shows one of the "electric launches" similar to those which proved such a success on the lagoons at the Chicago World's Fair, and which are now built for general sale. These boats are very much like small steam or gasoline launches, but instead of a hot steam boiler and engine, or a disagreeable gasoline engine, an electric motor, which may be put out of sight under the floor, is operated by electric current from a storage battery, the cells of which are placed under the seats and floor so as to act as ballast. The boat is not so independent as a steam or gasoline launch, as the battery must be charged every day to keep it in good order for operating, but electric launches are convenient for use wherever current can be obtained for charging the batteries.

During the past two or three years the automobile has been so far developed that it has become a familiar sight on the streets of most of our cities and towns. These horseless carriages are driven by steam, gasoline, and electricity. The latter method is popular in the large cities where electric current may be readily obtained for charging the storage batteries, and it has given reasonably satisfactory results. The motor of from one-half to two or more horse power is usually geared to one of the axles of the carriage and is supplied with power from a storage battery stored neatly under the seat. The motor is controlled by a rheostat, the handle of which is within easy reach of the driver. Such vehicles, one of which is exhibited in Figure 231, have not yet proved themselves to be so efficient that they seem likely to drive all the cab and dray horses from our city streets, after the manner of the electric railway, which, within the space of ten years, caused the street-car horse to become an oddity.

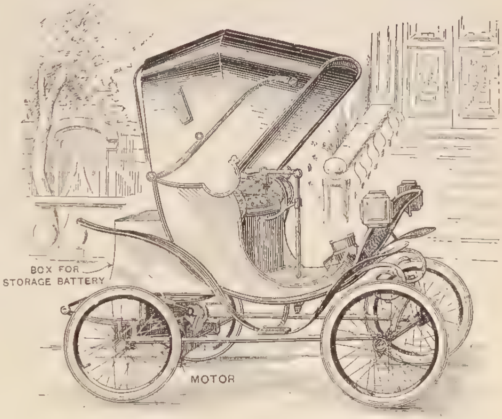

FIG. 231. — Electric Automobile.

## QUESTIONS

1. How long has it been since electric lighting plants became common?
2. About when was the first central station put in operation?
3. What changes have been made in the general construction of dynamos during the past twenty years?
4. Where was the first large station of the world located? When was it started?
5. How do the "Jumbo" dynamos compare with those of to-day?

6. Describe a central station suitable for furnishing light and power to a small city.

7. What instruments are used on a station switchboard? What are bus bars?

8. How are shunt dynamos thrown on to the bus bars, or into parallel?

9. What happens if a dynamo is thrown into parallel with another before it has developed full pressure?

10. What happens if alternators are thrown into parallel without synchronizing?

11. Why are double pole switches almost always used on high pressure circuits?

12. Why is it desirable to operate dynamos in parallel?

13. How are the feeders arranged in an alternating current station where the generators are not run in parallel?

14. What is the process of cutting a dynamo out of circuit? Why is the load first removed?

15. When was the Richmond electric railroad constructed?

16. Give a brief history of the development of the electric railroad.

17. What is a trolley wire? A trolley?

18. Describe the complete electric circuit in a street railway.

19. What special features must be included in the design of street railway motors?

20. Why are two motors used on a four-wheeled car?

21. Why is approximately 500 volts pressure found most suitable for electric railways?

22. How are very long electric railways supplied with power without undue loss in the wires?

23. What is a track bond? Why are electric railway rails bonded?

24. To what purposes may heavy electric locomotives be put?

25. How are output records kept in large electric stations?

26. Why are recording voltmeters especially useful in a lighting station?

27. In what special respect does the load of an ordinary electric railway power plant differ from that of an electric light plant?

28. How may a storage battery be used to smooth the load curve of an electric station?

29. What methods are used for controlling street car motors?

30. Why is the series-parallel method of control of advantage over others?

31. On what does the torque of a series motor depend?

32. On what does the speed of a series motor depend?

33. Describe a motor "starting box."

34. Describe the operations of starting and stopping a motor.

35. For what purposes may electric motors be advantageously used?

36. Why do electric motors form ideal devices for driving the machinery of manufactories?

37. How should the motors be arranged in an electrically driven machine shop?

38. How is power supplied to an electric launch?

39. Describe an electric automobile.

# CHAPTER XIX

## THE TELEGRAPH; THE TELEPHONE; ELECTRIC BELLS

**290. Historical.** — The electric telegraph, as we know it, is to a large degree a growth from the discoveries of Professor Joseph Henry, which were directly applied to the purposes of telegraphy by S. F. B. Morse and his assistants; and to Morse must be rightfully ascribed the credit for the finished telegraph of to-day. His name is written irrevocably in the tale of the world's progress, and wherever telegraphs are found the name of Morse accompanies them.

Numerous attempts to produce an electric telegraph failed during the latter part of the eighteenth century and the first three decades of the nineteenth. The earlier ones were dependent upon the use of frictional machines (which proved to be unreliable) as the sources of electricity, for Volta's great discoveries, which resulted in the electric battery, were not made until the closing years of the eighteenth century and the opening years of the nineteenth.

Volta's discoveries were followed by that of Oersted, wherein he showed the magnetic effect of the electric current[1]; and close on the heels of these followed, in 1820, Ampère's demonstration that electric currents exert magnetic forces upon each other[2]; Arago's and Davy's observations that steel needles may be magnetized by the magnetic effects of electric currents[3]; and Schweiger's discovery of the increased magnetic effect caused by multiplying the electric turns.[4]

In 1825 the essential property of the electromagnet was discovered by Sturgeon,[5] and about 1830 Henry made the magnet as it stands to-day. Henry also laid civilization under unextinguishable debt by showing the way to the most powerful use of electric batteries and the working of electromagnets at great distances. These discoveries he put into actual use in the construction of and distant working of relays and electric bells, and otherwise extended the knowledge of the laws of electricity and magnetism.

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[1] Articles 119 and 120.
[2] Articles 124 and 143.
[3] Articles 125 and 126.
[4] Article 124.
[5] Article 126.

**291. Morse's Invention.** — The time was ripe for a practical electromagnetic telegraph, and early in 1838 Morse had reached a satisfactory conclusion of his series of inventions begun in 1832. His earlier devices were clumsy and complicated, but in the apparatus of 1838 the principles embodied in the earlier attempts were accompanied by proper mechanical designs, and worked well.

In these devices the magnet was not unlike that of the present day, but all signals were designed to be recorded on slips of moving paper. Much battery power was required for use with the devices, and it was impossible to transmit the necessary operating current long distances, and Morse, therefore, introduced **Relays** into his circuits. That is, instead of causing his recorder magnets to be directly worked from the line, he introduced a delicately constructed relay magnet which was worked by the line current, and this relay in turn controlled a local circuit containing the recorder magnet and a **Local Battery.**

Since Morse's day the recorder has been displaced by a **Sounder,** and other simplifications have been made, but the essence of the apparatus has not been changed.

**292. First Telegraph Line.** — The first telegraph line built by Morse was constructed by means of an appropriation passed by Congress in 1845, and the line was erected to connect the cities of Baltimore and Washington.

First attempting to lay the wires in the ground, encased in lead pipes, the constructors found themselves in difficulty from imperfect insulation, and they resorted to the plan of stretching cotton-covered wires overhead, on poles erected for the purpose. These wires were supported at the poles on insulators made from two glass plates which were later replaced by glass bureau knobs. The construction was crude, but essentially the same as the telegraph and telephone construction of to-day.

The line was opened on May 24, 1844, with the much-quoted message, "What hath God wrought !," and after nearly a year of experimental demonstrations it was opened to public traffic. It soon became the centre of interest throughout the country, and the construction of telegraph lines was quickly undertaken in various parts of the land.

**293. Needle Telegraph.** — Almost coincident with the development of the Morse telegraph in America, the *needle telegraph* was put upon a practical footing in England. The operation of this apparatus depends upon the deflection of a magnetic needle by an electric current in a surrounding coil. By making and breaking the circuit, the needle may be caused to swing and then to come to rest, or by reversing the current the needle may be caused to swing from one side to the other; and signals may be indicated by the motions of the needle. The needle telegraph came into considerable use, but it has now been almost completely superseded by the Morse telegraph and the code of signals invented by Morse, which consists of conveniently spaced dots and dashes, and is called the Morse alphabet.

It may be properly added here that the recognition of the correctness of the laws of current flow enunciated in 1827 by Ohm, though tardy, was still of great service in the later development of telegraphy.

**294. The Telegraph Key.** — The Morse system of telegraphy at the present time has four elements connected in series:

1st, a **Battery** or other source of an electric current;

2d, a **Key**, by means of which the electric circuit may be made and broken to produce **Signals**;

3d, a **Line** of wire running from the point at which the signals are produced to the point where the signals are to be received;

4th, an electromagnetic **Relay**, **Sounder**, or **Register**, by means of which the signals may be distinguished or recorded.

The battery ordinarily used in telegraphy is the common gravity form described in Article 49, but galvanic batteries, during the past few years, have been widely replaced in telegraph service by small dynamos.

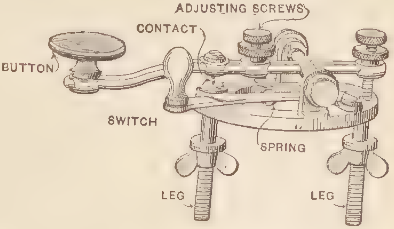

FIG. 232. — Ordinary Form of Telegraph Key.

The ordinary form of telegraph key is shown in Figure 232. This consists of a lever, which is pivoted so that it may be moved through a small vertical range by pressing one's fingers upon the button at its end (the left hand of the figure). The spring shown at the centre of the figure tends to keep the lever at the upper end of its stroke, so that an **Operator,** in making signals with the key, needs only depress the lever and it will return to its normal position upon removing the pressure. The operator's fingers are therefore placed on the button in the way shown in Figure 233. The left-hand **Leg** of the key is connected to a contact point which is seen directly above the leg (Fig. 232), and which is insulated from the frame. The lever carries a corresponding contact point directly above the insulated one. The upper contact point is in electrical contact with the right-hand leg through the metal of the lever and frame. When the key is connected into a circuit by cutting the circuit wire and attaching the two ends to the two legs of the key, the circuit may be made and broken at the will of the operator by depressing or raising the lever. Some keys are made without legs, but with binding posts for the connection of the wires.

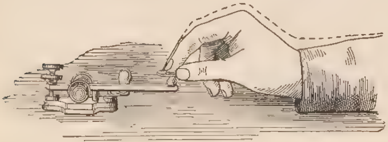

FIG. 233. — Proper Position of Operator's Hand in holding Telegraph Key.

As ordinarily arranged, a telegraph circuit is broken only at the time of making signals; consequently a switch is placed on the key so that the circuit can be closed when the key is not in use. The handle of the switch is shown in Figure 232, just to the left of the contacts. With this arrangement of the circuit it is possible to place a number of **Stations** in series on one line (Fig. 234); and since the circuit is normally complete, — that is, it is always complete when not in use, — the operator at any station may signal any other at any time, provided no other operator is using the line.

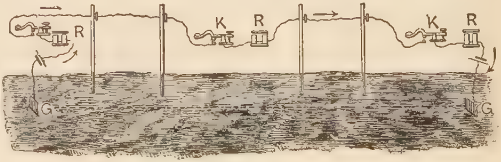

FIG. 234. — Diagrammatic Illustration of Telegraph Line with Three Stations.

**295. The Telegraph Line.** — The current used in telegraphy is quite small — it does not often exceed fifty milliamperes,[1] — consequently it is possible to satisfactorily use the earth for one side of the circuit. A telegraph line, therefore, ordinarily consists of a wire supported on wooden poles and running from station to station. At its ends the wire is connected to the earth by means of **Ground Plates**, as shown at *G*, *G*, in Figure 234.

The wire used is generally made of the best galvanized iron, but for some short lines steel wire is used, and for some of the most important lines between large cities copper wire is used. Wires as large as No. 4 Birmingham wire gauge and as small as No. 10 are sometimes used, but the usual size is No. 6 or No. 8. The choice of the size and kind of wire depends largely upon the length and importance of the line, upon which also depends the amount of battery power which is necessary to operate the signals and the care which is lent to keeping the line in good condition.

**296. Recording Register.** — In the earlier days of the Morse telegraph it was thought necessary, as already explained, to receive the signals constituting a telegraphic message in a permanent form by means of a recording register. One of the improved registers is shown in Figure 235. This consists of a case containing a horseshoe electromagnet, the windings of which are connected in series with the telegraph circuit. Over the poles of the magnet is an **Armature** of soft iron, which is held against a stop by the pull of the magnet when the current flows through the circuit. When the current is interrupted by means of a key, as in sending signals, the electromagnet loses its magnetism, and the armature is no longer attracted, so that a small spring which is

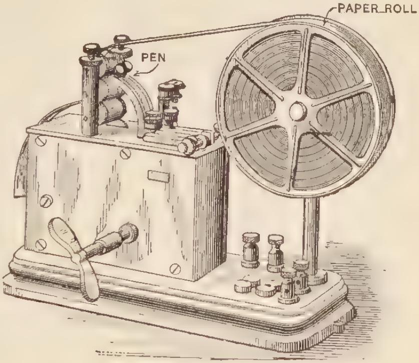

FIG. 235. — Recording Telegraph Register.

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[1] Article 194.

attached to it is able to pull it back from the stop. Thus, as current impulses are sent along the line by making and breaking the circuit at a key, the pulls of the magnet and of the spring alternately draw the armature forward and backward.

The movement of the armature is recorded or registered by means of a pen or a blunt point on a strip of paper which is automatically fed from the roll shown in the figure by a clockwork mechanism that is inside of the box. This paper tracing of the signals may be read by the receiving operator and translated into ordinary language upon a telegraph-blank, and the latter is delivered to the person for whom the message is intended.

**297. Telegraphic Signals.** — Telegraphic signals are made up of a combination of long and short current impulses, which are made by pressing the sending key at proper intervals and for proper periods, and which are recorded on a register as long and short dashes. Each combination of dashes represents a letter of the alphabet or a certain much-used word or phrase. The **Morse Alphabet**, as it is called, which is used in this country, is given below (Fig. 236).

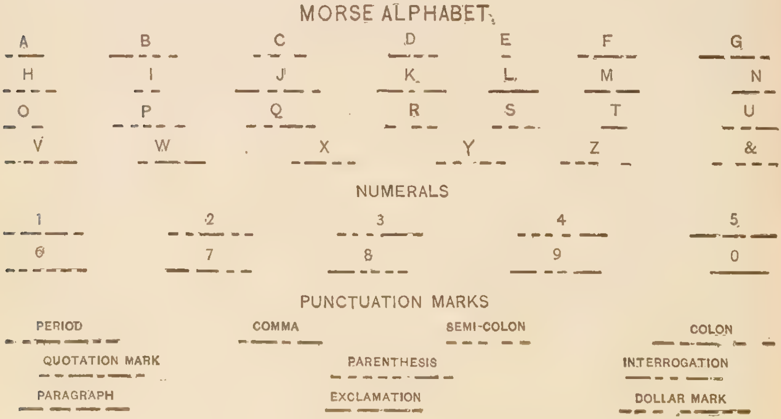

FIG. 236. — Morse Alphabet as used in America.

**298. Telegraph Sounders.** — As the Morse telegraph came into considerable use, the operators found that they could read the signals passing over the line by listening to the clicks of the register armature as it moved back and forth between its stops under the influence of the current impulses. The paper roll was, therefore, abandoned, as "reading by sound" was quicker and more convenient than translating the message from the paper tracing of the signals.

To make reading by sound as easy as possible, the working mechanism of the register was altered into that of the **Sounder**, and Figure 237 plainly shows its arrangement. The armature, which is of soft iron, has attached to it a substantial brass bar. This bar is pivoted at its right-hand end, as shown in the figure, so that its left-hand end may move up and down between adjustable stops, as shown. To the right-hand end of the bar is attached a spring which draws the bar against the upper stop when no current is flowing in the magnet. The large cylinders shown about the centre of the figure compose the magnet. This magnet consists of two cores of iron about three-eighths of an inch in diameter and one inch and a half long, wound with wire and covered with black paper or a short piece of hard rubber tube. The cores are screwed fast to an iron base so as to make a horseshoe electromagnet. The armature is shown at the top of the figure, above the magnet.

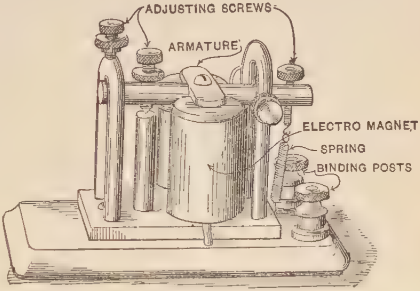

FIG. 237. — Telegraph Sounder.

When current flows in the magnet winding, the armature is attracted and the bar drawn against the lower stop. As the bar moves back and forth it makes a sharp click whenever it strikes one of the stops. The strength of the spring is adjustable by means of a screw, so that the sounder may be adjusted for use within a certain range of currents of different strengths.

To successfully read signals from a sounder, much experience is necessary, but operators become very expert by long practice. It is necessary in reading to distinguish between the clicks of the armature against the top and bottom stops. A little consideration will show that the length of time between the clicks when the armature strikes the bottom stop and when it strikes the top stop distinguishes between dots and dashes, since the dots and dashes represent intervals during which current is flowing through the magnet. The interval of time between the top click and the bottom click represents the spacing between the dots and dashes, because the spacing represents intervals during which no current flows, or during which the signal key is open.

**299. Relays.** — Telegraph sounders require only a fraction of an ampere to operate them, but to cause that fraction to flow through a long line, which necessarily has a high resistance, requires the use of a battery of a very large number of cells. This is undesirable, because the cells are expensive to buy and to keep up.[1] Long telegraph lines are, therefore, furnished with instruments which operate like sounders, but which are made very sensitive by placing a great many turns of fine wire on their magnets, so that they may be satisfactorily operated on as little current as eight or ten milliamperes. These instruments are called **Relays** (Fig. 238).

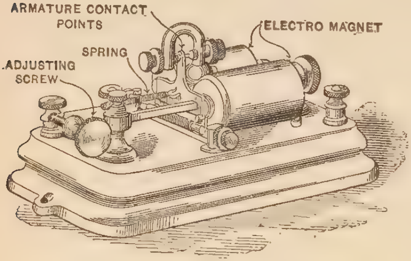

FIG. 238. — Telegraph Relay.

Reading signals directly from a relay is not usually attempted, as the motion of its armature is so delicate that it makes very little sound, but the armature and one of its stops are arranged as a part of a **Local Circuit**, which contains a sounder and a couple of gravity cells (Fig. 239). As the relay armature moves back and forth it makes and breaks the local circuit and reproduces in it the signals which pass over the main line. The sounder in the local circuit gives the signals exactly as they pass over the line.

**300. Multiple Telegraphy.** — To still further economize in long and important lines, arrangements are made to send more than one message at a time over each wire. When a telegraph wire is arranged so that two messages may be transmitted over the wire at once, one being sent from each end, the wire is said to be **Duplexed.** When it is so arranged that both messages may be sent from one end, the wire is usually said to be **Diplexed.** Diplexed wires are not ordinarily used, except in combination. When a wire is arranged so that four messages may be transmitted over it at once, two being sent from each end, it is said to be **Quadruplexed.** In arranging a **Quadruplex,** a combination is practically made of a duplex and a diplex arrangement.

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[1] Article 54.

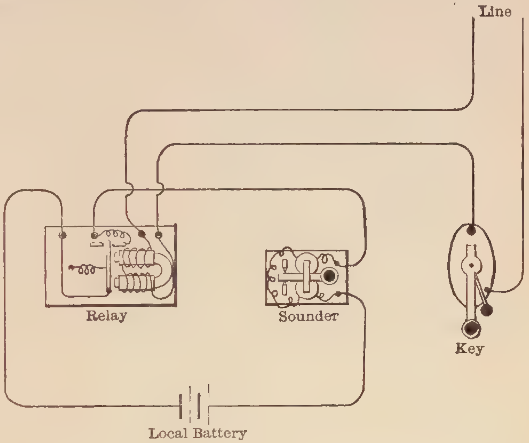

FIG. 239. — Illustration of Apparatus at Telegraph Station, including Key, Relay, and Local Circuit, with Battery and Sounder.

**301. Duplex Telegraphy.** — The commonest arrangement for duplex telegraphy requires a special relay, which is connected as shown in Figure 240. It is seen that three points of connection are made to the wire which is wound on the electromagnet of the relay, one point at each end of the wire, and a third at the middle of the wire. One-half of the wire is wound on each leg of the electromagnet in the usual way. If a current is passed through the wire from one end to the other, as indicated by the arrow-heads on the wire, the relay acts as a common relay.

If a current is sent into the relay from the middle point, the current divides, as indicated by the dotted arrows, and the two parts pass through the windings on the two legs of the electromagnet *in such a way that their magnetic effects are in opposite directions.* If the two divisions of the current are equal, their magnetic effects neutralize each other, so that the armature of the relay is not affected.

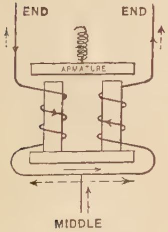

FIG. 240. — Diagram of Differential Relay for Duplex Telegraphy.

Such a relay is called a **Differential Relay**. The exact arrangement of the windings on a differential relay may vary considerably, but the purpose and effect of all arrangements are exactly the same as described.

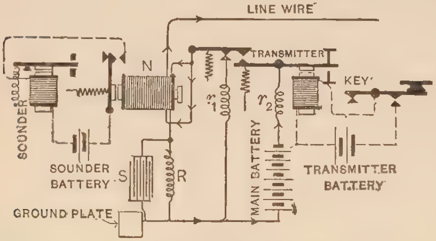

FIG. 241.—Diagram of Instruments and Circuits at a Telegraph Station, arranged to operate by the Differential Duplex System. *N*, Differential Relay; $r_1$ and $r_2$, Special Resistances.

Figure 241 is a diagram of the connections made at a telegraph station for duplex telegraphy using a differential relay. This arrangement is often called the **Differential Duplex.** The figure shows by the arrowheads that the current sent into the line at the station divides in the relay belonging to that station, and half of it passes to the ground through the resistance (*R*) and back to the battery. The other half of the current goes through the line and the relay of the distant station for which the signals are intended, and returns to the battery by way of the earth.

The two halves of the current pass through the coils of the home relay in opposite directions and neutralize each other's magnetic effects. A message sent from the home key, therefore, does not affect the home relay. That part of the current which goes into the line passes through the winding of the distant relay in the usual manner, so as to make a signal. In this way the operator at any station on a line can signal another without affecting his home relay. Two messages can therefore be transmitted at the same time in opposite directions between two stations without interference. This, of course, requires two operators, one to send and one to receive the message at each station. The figure shows a special device for making the signals, which is called a **Transmitter.** This is explained in the next article.

In order that a differential duplex system may work, it is absolutely necessary that the current in the relay divide quite accurately into halves. This is effected by properly adjusting the resistance of the rheostat *R* in the home branch of the circuit. The branch of the circuit at each station containing the resistance *R* is called the **Artificial Line**, since it is made to represent as far as possible the condition of the actual line in order that the duplex may work satisfactorily. The resistance of the line is easily balanced by making the resistance *R* so that it may be adjusted by plugs to suit the condition of the line. Certain smaller resistances ($r_1$ and $r_2$ in the figure) are also used in the home circuits to smooth the action of the transmitter in making and breaking the circuit.

The electrostatic capacity of the line affects the rise and fall of the current in it as the signals are transmitted, and in order to get the best results with the differential relay the artificial line is arranged with a condenser, *S*, connected in parallel with the resistance *R*, the capacity of which balances that of the line. This condenser is usually made of sheets of tin-foil insulated by sheets of thin mica or paraffined linen paper, and the capacity connected into circuit may be adjusted by means of plugs.

When a telegraph circuit is arranged for duplex working, it is necessary to have a line battery at each of the stations. For simple working all the battery may be placed, if desired, at a single point along the line.

**302. Diplex Working.** — When a line is arranged for diplex working, two keys are placed at the sending station and two relays are placed at the receiving station. One of these relays, called the **Polarized Relay**, has a permanently magnetized steel armature. When the armature, which lies across the poles of a horseshoe electromagnet is permanently magnetized or polarized, it is attracted when the current flows in one direction and repelled when the current flows in the opposite direction.

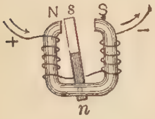

FIG. 242. — Diagram of Polarized Relay with Current flowing from Left to Right.

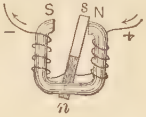

FIG. 243. — Diagram of Polarized Relay with Current flowing from Right to Left.

Advantage may best be taken of this by placing the polarized armature between the poles of the electromagnet, as in Figures 242 and 243. The end of the armature will then stick against either pole indifferently when no current flows, if it is not restrained by a spring. When a current flows in one direction, the end of the armature will move up to one pole, and when the current is reversed, the armature will move over to the other pole, as shown in the figures.

A polarized relay made upon this principle may be operated by signals which are given by reversing the current in the circuit instead of making and breaking the circuit as in simple telegraphy.

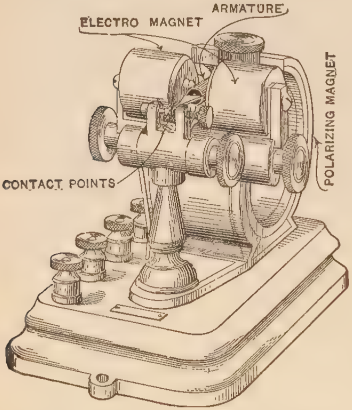

FIG. 244. — Commercial Form of Polarized Telegraph Relay.

Figure 244 shows a common form of polarized relay in which the armature is kept polarized by means of a strong permanent magnet to which it is attached. A key for sending signals by reversing the current is called a **Pole Changer.**

It is possible to send signals to a common or neutral relay over the same line as that used with the polarized relay, without interfering with the action of the latter. In order that the currents which actuate the polarized relay shall not also work the neutral relay, the latter is adjusted to respond only to a current which is greater than that required to actuate the polarized relay, and we thus have a diplex arrangement. Hence the operation of the diplex arrangement depends upon the use of currents of two strengths. One of these currents is

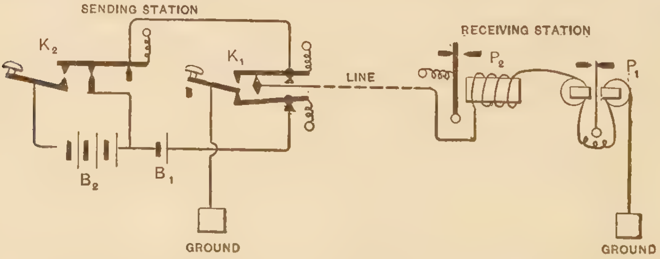

FIG. 245. — Diagram of Instruments and Circuits at Sending and Receiving Telegraph Stations arranged to operate by the Two-current Diplex System. $B_1$, Small Battery; $B_2$, Large Battery; $K_1$, Pole Changer and Key; $K_2$, Transmitter and Key; $P_1$, Polarized Relay; $P_2$, Neutral Relay.

quite weak and is reversed in sending signals, so that a polarized relay is used with it; the other current is stronger and is increased and decreased by the sending key in sending signals to the neutral relay, instead of making and breaking the circuit, since doing the latter would interfere with the signals sent to the polarized relay.

A key arranged to increase and decrease the current in sending signals is usually called a **Transmitter.** The increase and decrease of the current is gained by alternately connecting into circuit a large and a small battery (Fig. 245). In order that common telegraph keys may be used by the operators in sending messages by the diplex arrangement, it is usual to work the pole changer and transmitter by means of electromagnets like sounders, connected individually in local circuits in series with the sending keys. Figure 245 is a diagram of the connections at the sending and receiving stations upon a diplex telegraph line.

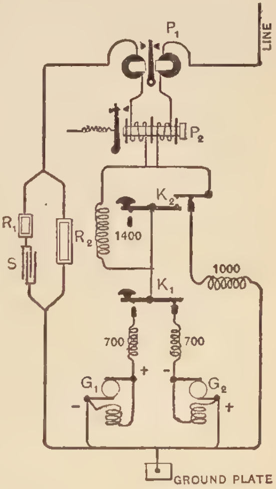

FIG. 246. — Diagram of Instruments and Circuits at Telegraph Station arranged to operate by the Quadruplex System. $G_1$, $G_2$, Dynamos; $K_1$, Pole Changer; $K_2$, Transmitter and Key; $P_1$, Polarized Differential Relay; $P_2$, Neutral Differential Relay; $R_1$, $R_2$, Adjustable Resistances; $S$, Condenser.

**303. Quadruplex Telegraphy.** — The commonly used quadruplex system is essentially a combination of the differential duplex and two-current diplex which have just been explained. A diagram of the circuits at a quadruplex station is shown in Figure 246.

It is to be seen in the diagram that *polarized and neutral relays of the diplex arrangement are used, but they are wound in differential fashion.* This makes it possible to send two messages from a station without interference with each other (diplex), and also without interference with receiving two messages at the same station by means of the differential instruments.

The key arrangements for the quadruplex system are the same as those of the diplex system, so that a pole changer and transmitter are used, though for simplicity they are not fully shown in Figure 246.

The figure shows the use of dynamos in the place of batteries. The coils marked 700 and 1000 are resistances which take the place of the resistances $r_1$ and $r_2$ in Figure 241. The coil marked 1400 is used to reduce the current which flows through the neutral relay between the signals, and it fulfils the purpose of the division of the battery into a large and a small section.[1] The numbers represent the resistances of the coils in ohms. The signals for the neutral relay are made by alternately cutting this large resistance into and out of the circuit by the transmitter. The action can be understood by an examination of the illustration.

For satisfactory quadruplex working the artificial line must be kept well adjusted, or trouble is experienced from blurring the signals in the differential instruments.

**304. Miscellaneous Telegraph Systems.** — Another duplex arrangement, which depends for its operation on a balance similar to that of a Wheatstone bridge, is often used on ocean cables. The arrangement is shown in Figure 247. In this system the relay is located at *L*. In the arms *AC* and *AB* of the triangle, fixed resistances are located; *R* is a variable resistance, and *S* is a condenser which shunts *R*. Now, according to the principle of the Wheatstone bridge, if the resistance in *AC* is to the resistance in *AB* as the resistance of the line is to the resistance *R*, no current will flow from the home battery through the relay *L*. Current from a distant battery will, however, work the relay, since it will come in from the line to *C*, where it will divide, and a part will go around through *CA* in its path to earth, but the greater part will pass directly through the relay, which offers a path of lower resistance. The condenser *S* is used to balance the effect of the capacity of the line.

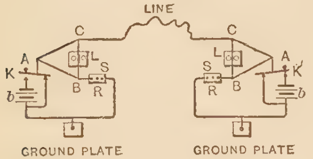

FIG. 247. — Diagram of Circuits for the "Bridge Duplex" Arrangement.

A duplex system may also be operated by means of differential polarized relays. This is practically the same in operation as the differential duplex systems already explained, but pole changers are used to send the signals, and polarized relays are used to receive them.

Various plans for sending more than four messages over one wire have been devised, but they have been too complicated to be successful in operation, and can receive no attention here. When more than four messages are sent over a wire, the arrangement is ordinarily called **Multiplex Telegraphy**, though this title really applies to all telegraphic arrangements where two or more messages are sent over a wire at one time.

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[1] Article 302 and Figure 245.

Methods have also been devised for sending messages by machines instead of by hand. Such machines are used to a considerable extent for special work, such as sending press despatches, stock quotations, and similar purposes. It is usual for machine-sent messages to be received by special machine recorders, which print the messages either in Morse characters or directly in the English alphabet. Where machines are used in telegraphy, the arrangement is ordinarily spoken of as **Automatic Telegraphy.**

Other devices have been invented by means of which a written message or sketch may be transmitted exactly as it is written or drawn. These are ordinarily spoken of as devices for **Autographic Telegraphy.** The most successful of these arrangements thus far is the Gray's **Telautograph**, but none of them have yet come into general use, on account of their complications.

**305. Ocean Telegraphy.** — Before passing from the subject of telegraphy to the closely allied one of telephony, it is worth while to say a word concerning **Submarine** telegraphy. The first successful cable was laid from America to Europe in 1866. The result is largely due to the tireless energy and exceptional grit of Cyrus W. Field, an American capitalist. Mr. Field first entertained the thought of carrying "the line across the ocean" in the early part of 1854. He at once formed a company, and, though met by ridicule and rebuffs on every hand (dealt equally by scientific men and capitalists), he succeeded in enlisting the aid of friends on both sides of the Atlantic and the interest of the governments of the United States and Great Britain. After several attempts, and the partial loss of two cables, a cable was finally laid in 1858 across the ocean from Ireland to Newfoundland. It transmitted congratulations between the President of the United States and the Queen of England; worked with difficulty three weeks; and then became silent.

This failure, due to weakness in the construction of the cable, was a crushing blow. The company had spent millions and its supporters were losing confidence, but Field had the same unconquerable determination as Morse. He managed to maintain the enterprise, and as early as 1863 arrangements were put on foot looking to the laying of another cable. This delicate work was begun in 1865 from the noted ship *Great Eastern*. In the first trial one cable was entirely lost by parting at sea when nearly laid, but after several further unsuccessful attempts the laying of a cable was properly accomplished in 1866, and it was put into successful operation. The lost cable of 1865 was soon after grappled for, found, brought to the surface, spliced, and completed; and it, too, was put into operation. These two cables, and numerous later ones, have continued in satisfactory service.

**306. Working of Ocean Cables.** — The cables for submarine telegraphy consist of one or two copper conductors embedded in a thick insulation of gutta-percha, or an equally good insulator, which is protected from injury in handling by a thick covering of jute fibre and one or more wrappings of heavy iron wire. The conductors are made of several strands of small copper wire twisted together for the purpose of making the cable flexible.

The apparatus which is now used for receiving the signals is of a recording type of D'Arsonval galvanometer called a siphon recorder. It is infinitely more delicate and sensitive than that described in Article 296. The first successful receiving apparatus was designed by Lord Kelvin. It consisted of a very fine galvanometer of high resistance, which by the swing of its needle moved a very light feather quill that made the record; or, the galvanometer alone was used, and an operator read the signals directly from the swing of the needle. The Kelvin galvanometers, developed during the laying of the early cables, still remain models of inventive skill and constructive perfection.

The recording devices for ocean cables may either be placed in direct connection between the end of the cable and the ground, or the cable may be connected to one set of the plates of a condenser. The other set of plates is then connected through the galvanometer to the ground. In this case the charge passing into the condenser from the ground, under the influence of the charge from the cable, causes the galvanometer deflection. The transmitter consists essentially of a key that either throws one terminal of a strong battery directly upon the cable, or charges the plates of a condenser connected as explained above. One terminal of the battery must, of course, be connected to the ground.

**307. Duplex Cable Working.** — It is usual nowadays to work cables duplexed by means of an arrangement of circuits called the "bridge duplex" system, which is described in Article 304 and illustrated in Figure 247. The receiving instruments at each station are represented by the letter *L*, and the sending key and battery by the letters *K* and *b*. The devices marked *R* and *S* are resistances and condensers for the purpose of adjusting the operation of the instruments, and fixed equal resistances are placed in the arms *AC* and *AB*.

When either key is depressed so as to put current upon the cable, the home receiving instrument is not affected, provided the resistance and capacity of the artificial cable, *R*, *S*, are equal to those of the real cable added to those of the arrangements of the far station. This is in accordance with the law of the Wheatstone bridge:

$$\text{If } \frac{AC}{AB} = \frac{\text{Real Cable}}{\text{Artificial Cable}}, \text{ no current will pass through } L.$$

Now, when a current comes into a station from the cable, its easiest path to the ground, by which it may return to its battery, is through the siphon recorder *L*; and the signal record is a result of this current flow.

## QUESTIONS

1. Who invented the modern telegraph? When?
2. Give a brief history of the discoveries in electricity which made possible an electromagnetic telegraph.
3. Who was Henry? What did he do toward laying the foundation of the telegraph?
4. When was the first Morse telegraph line built? Tell about it.
5. What is the needle telegraph? How does it work?
6. When did Ohm announce the law that bears his name?
7. What are the essential elements of an electric telegraph?
8. How is the current obtained for telegraph lines?
9. Describe a telegraph key.
10. How are telegraph signals made?
11. What is the advantage of having the current flow through the line at all times except when signals are being sent?
12. Why must a switch be used with the key?

13. What kinds and sizes of wire are used in telegraph lines?
14. How does a recording register work?
15. How are letters and words composed of telegraph signals?
16. Describe a sounder.
17. How are signals read from a sounder?
18. Describe a relay.
19. How are relays used? What is the local circuit?
20. Why are relays used?
21. What is multiple telegraphy?
22. What is duplex telegraphy?
23. What is diplex telegraphy?
24. What is quadruplex telegraphy?
25. What is a differential relay? How is it used?
26. What is the principle of a differential duplex system?
27. What is the artificial line?
28. What is a pole changer? What is it for?
29. What is the principle of a two-current diplex system?
30. What are the principles of a quadruplex system?
31. How must the relays be wound for differential duplex working?
32. Explain the principle of the bridge duplex.
33. Why does the home relay in the bridge duplex not record the signals sent from the home transmitter?
34. What are automatic and autographic telegraphs?
35. When was the first Atlantic cable laid?
36. What troubles did Mr. Field encounter in laying a cable?
37. How are ocean cables worked?

**308. The Telephone.** — Unlike telegraphy, which is nearly the oldest commercial application of electricity, the telephone is one of the later commercial applications. The word "telegraph" comes from two Greek words which mean, when combined, to write at a distance, while "telephone" comes from two Greek words which mean to speak at a distance. The first telephone that can be given the credit of commercial success was invented by Alexander Graham Bell, and was privately exhibited by him at the Centennial Exposition at Philadelphia in 1876. Dr. Elisha Gray applied for patents on a telephone mechanism at the same time, and the nearly simultaneous invention of the instrument by the two noted men gave rise to a famous patent law suit.

Since that time the usefulness of the telephone has been greatly increased by other inventions which make its service more perfect. In its improved form, it has added wonderfully to the ease and quickness with which many kinds of business may be transacted, and it may be said to have revolutionized many of the processes of doing business.

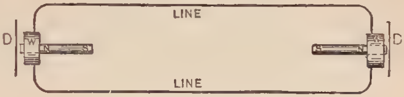

FIG. 248.— Illustration of Bell's Early Telephone System.

The telephone originally exhibited by Bell consisted of two instruments quite similar to the ear pieces or **Receivers** which are now used. One of these instruments was used as a receiver and the other was used to talk into, or as a **Transmitter**, and the two were connected by wires (Fig. 248).

The construction of these instruments may be best explained by reference to Figure 249, which is an illustration of a late type of Bell receiver. In this figure *R* represents a rubber case, *NS* a magnet tipped with pieces of soft iron, and *WW* spools of very fine wire slipped over the soft iron tips of the magnet and connected to the binding posts, *PP*, at the end of the rubber case. *D* is a **Diaphragm** or disk made of thin varnished iron. This diaphragm is firmly clamped all round its edges in such a position that its centre is very close to the poles of the magnet *NS*. When one of the instruments is brought close to a speaker's mouth, the waves of sound caused by his speech strike the diaphragm and cause it to vibrate, or move back and forth. The speaking end of the instrument is formed into a **Mouthpiece** of such a shape that it gathers in a large volume of the waves of sound, and concentrates their effect upon the diaphragm.

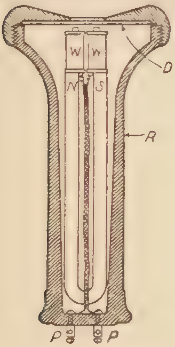

FIG. 249. — Sectional View of Bell Telephone Receiver.

Most of the magnetic lines of force[1] belonging to the magnet pass through the coils of wire, *WW*, and some of them enter the iron diaphragm on their path to the opposite pole. As the diaphragm vibrates from the effect of a voice, it moves back and forth in front of the magnet. These vibrations are very, very small,— entirely too small to be seen by the eye,—but they are of sufficient extent to cause the number of lines of force which enter the disk to increase considerably as it approaches the magnet, and decrease as it moves away from the magnet. In this way the distribution of the lines of force around the end of the magnet is altered with each movement of the disk, and the number of lines of force which pass through the coil, *W*, of wire on the magnet is increased or decreased at the same time.

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[1] Articles 84 and 85.

It is an experimentally determined fact that when a change occurs in the number of lines of force passing through a coil, an electric pressure is set up in the coil.[1] This pressure is in one direction when the number of lines of force passing through the coil is increased, and in the opposite direction when the number is decreased. Consequently the movements of the Bell telephone diaphragm set up electric pressures in the telephone coil, and when this coil is connected by wire to the coil of another telephone, as in Figure 248, waves of current flow through the circuit which correspond in a general way to the waves of sound set up in front of the diaphragm of the first telephone. As these current waves flow through the coil of the second telephone, they increase and decrease the strength of its magnet. This alters the amount of the attraction which the magnet exerts on its diaphragm, and the diaphragm is, therefore, thrown into vibrations which correspond with the current waves. The result of these vibrations of the second diaphragm is to send out waves of sound like those which set the diaphragm of the first telephone to vibrating.

**309. Telephone Transmitters.** — The original Bell telephone is not sufficiently powerful as a transmitter to give satisfactory service, but it is an extremely sensitive and satisfactory receiver. The transmitters which are now generally used are, therefore, based on an entirely different principle.

When two bits of carbon are permitted to lie loosely against each other, the electrical resistance of their contact is very much changed when changes occur in the pressure of the contact; and also if a blunt metal point lies loosely against the carbon surface, differences of pressure at the contact cause variations in its resistance. Advantage is taken of this principle in the common telephone transmitter known as the Blake transmitter. Figure 250 is a diagram of such a transmitter. *M* is a mouthpiece, and $D$ is the diaphragm. Touching the back of the diaphragm is a piece of platinum wire, $p$, about $\frac{3}{64}$ inch in diameter and $\frac{1}{8}$ inch long, which is soldered into a hole at the end of a very fine German silver spring, $x$. The other end of this piece of platinum makes a loose contact at $C$ with the polished face of a carbon button which is suspended on a piece of very flexible watch spring, $y$. The amount of pressure at the contact is exceedingly small and may be very delicately adjusted by the screw which is shown near the bottom of the figure.

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[1] Articles 137, 138, and 140.

Platinum and carbon electrodes are used in this transmitter in preference to two carbon electrodes because there is less sparking between them than there would be between two carbon surfaces, and the conductivity of the surfaces is preserved for a longer time. The carbon button and platinum piece are represented by the two heavy black spots at $C$ in the figure.

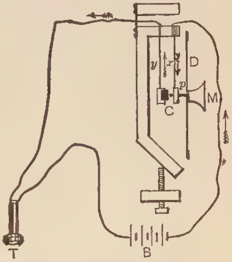

FIG. 250. — Diagram of the Commonly Used Microphone Telephone Transmitter.

If the diaphragm of this transmitter (which is commonly known as the Blake transmitter) is spoken to, it vibrates and causes the platinum point to press more or less lightly upon the carbon button and thus varies the resistance of the contact. If the transmitter is connected in a circuit including a battery and Bell telephone receiver, as shown in Figure 250, the current flowing in the circuit varies with the resistance of the carbon contact when the transmitter diaphragm vibrates. The current in the circuit is, therefore, thrown into waves which correspond with the vibrations of the diaphragm. As these waves of current pass through the coil of the receiver, they increase and decrease the strength of the magnet, and its diaphragm is thrown into vibration so that the original sounds are reproduced, as already explained in Article 308.

A transmitter in which two carbon electrodes are separated by granules of carbon is also commonly used. Such a one is illustrated in Figure 259.

**310. Microphones.** — Such a carbon contact as is used in a telephone transmitter is called a **Microphone**, and a transmitter in which it is used is often called a **Microphone Transmitter.** A very easily made microphone, in which both electrodes are of carbon, is shown in Figure 251. In this figure, *C* represents a short stick of carbon with pointed ends, which is held loosely between the carbon blocks *BB*. These blocks are a little countersunk so as to keep the carbon stick from falling out, and they are fastened to a thin piece of pine board, *S*. The whole may be mounted on a board. When this microphone is connected in circuit with a cell of battery, *B*, and a telephone receiver, *R*, by means of the wires which are attached to the carbon blocks, it will transmit sounds to the telephone. Such a rough microphone will not transmit speech so that it can be understood, but it will cause the telephone to sound for the slightest whisper.

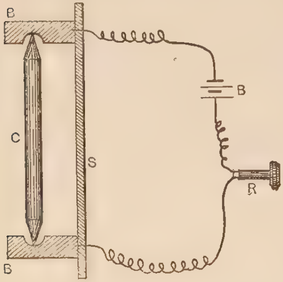

FIG. 251. — Diagram of a Simple Form of Microphone.

The credit of the invention belongs jointly to Professor D. E. Hughes, of Great Britain, and to Edison. Each discovered the properties of loose carbon contacts in 1878. The form of microphone constructed by Hughes was strictly a loose contact device such as is illustrated in Fig-

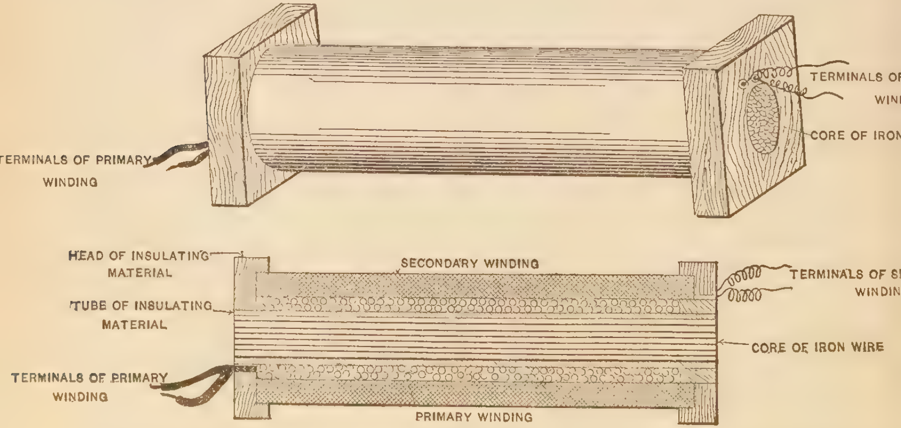
TERMINALS OF
WIN
CORE OF IRON
ERMINALS OF PRIMARY WINDING
HEAD OF INSULATING MATERIAL
SECONDARY WINDING
TERMINALS OF S
WINDIN
TUBE OF INSULATING MATERIAL
CORE OF IRON WIRE
TERMINALS OF PRIMARY WINDING
PRIMARY WINDING

FIG. 252. — Perspective View and Lengthwise Cross Section of Telephone Induction Coil.

ure 251, while that invented by Edison consisted of a soft mass of lamp black between two electrodes, one of which was attached to a telephone transmitter diaphragm.

**311. The Induction Coil.** — The ordinary microphone transmitter which is used in telephony is a rather delicate affair, and it cannot be worked with more than one or two battery cells. In order that long lines may be satisfactorily spoken over, the effect of the transmitter is intensified by means of *electromagnetic induction.* The *induction coil*[1] (Fig. 252), which is used for this purpose, also has the advantage of shutting out a scratchy sound which is caused by the transmitter. The primary winding of the induction coil is connected in series with the transmitter and battery and the secondary winding in series with the line.

**312. Complete Telephone Set.** — The commercial telephone system consists of much more than the transmitter and receiver with their accompanying battery and line. When telephones are used simply to connect two points, there must be located at each point a transmitter, a receiver, a battery cell, a means of operating an electric call bell at the other point, and a local call bell. This outfit is usually put up in a set like the familiar form shown in Figure 253. Here *A* represents the transmitter, *B*, the receiver, *C*, a box containing the battery cells, *DD*, the electric call bells, and *E*, a box containing a small dynamo with permanent magnets called a magneto,[2] which may be operated by a crank. The magneto is used for operating the call bells. When the receiver is not in use, it hangs on a hook (as shown) which is depressed by the weight of the receiver and moves electrical contacts which connect the bells and magneto into the circuit and disconnect the telephone instruments. When the receiver is taken from the hook, the latter rises so that the contacts cut the bells and magneto out of circuit and the telephone instruments into the circuit.

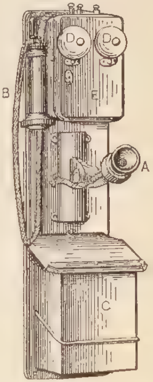

FIG. 253. — Telephone Set.

Figure 254 shows a diagram of the circuits in an ordinary commercial set with the bell and magneto connected across the line, that is, in the **Bridged** arrangement, as it is often called. The bell and magneto generator are connected in bridges across the line, the generator being provided with an automatic switch *S* that closes when the crank is turned. When the receiver is off the hook, as illustrated in the figure, a spring lifts the hook and brings the lever into contact with *N* and *O*, thus closing the battery circuit through the transmitter and connecting the receiver and the secondary winding of the induction coil into the line circuit.

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[1] Article 139.

[2] Article 196.

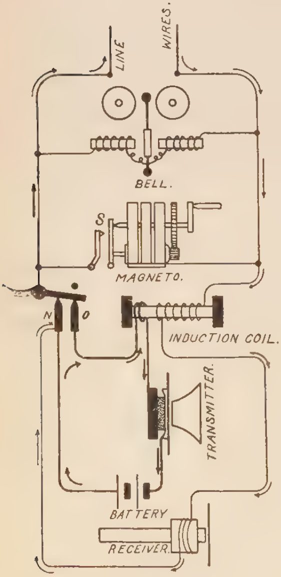

FIG. 254. — Diagram of the Electrical Connections in a Telephone Set.

**313. Telephone Exchanges.** — The use of telephones simply to connect two points is only a small part of the field of usefulness of the telephone. The great majority of telephones are used in connection with a **Central Exchange.** This is a place where many telephone lines centre and are brought to a **Switchboard** so that they may be readily connected with each other. By this arrangement each telephone user in a great city may have his telephone quickly connected with that of any other person. Each telephone user or **Subscriber** is supplied with a set such as is shown in Figure 253, and his line is run from the telephone set to a section on the switchboard at the exchange which bears the subscriber's individual number. When one subscriber wishes to speak with another, he turns the crank of his magneto, thus causing a signal at the switchboard. He then takes his telephone receiver from its hook, and when the switchboard attendant speaks, he asks her to connect him with the number of the second subscriber. This being done, the attendant rings the telephone bell of the second subscriber by means of a magneto, and this calls him to the telephone. When the conversation between the two subscribers is completed, one of them notifies the switchboard attendant by means of his magneto.

**314. Telephone Switchboards.** — Telephone switchboards are, as a rule, quite complicated, since an exchange is always connected to a large number of wires, and since the connections of the telephone wires must be arranged so that the operators and the subscribers are able to signal and talk to each other, as well as so that the subscribers' lines may be quickly connected together.

In the earlier and simpler forms of telephone switchboards the subscribers' wires on entering the exchange are each connected to a switchboard circuit which contains a **Spring Jack** and an electromagnet which controls a **Drop** or shutter. The circuit terminates at a ground plate. One form of the electromagnet with its *drop* is illustrated in Figure 255. The armature, *A*, of the electromagnet, *M*, has a hook, *D*, which ordinarily supports the shutter or *drop*, *P*, which is hinged at the bottom in a vertical position. When the subscriber sends current over the line from his magneto, the armature, *A*, is attracted, the drop is released and falls into the horizontal position illustrated in Figure 255, and thereby discloses the subscriber's number which is painted at its back.

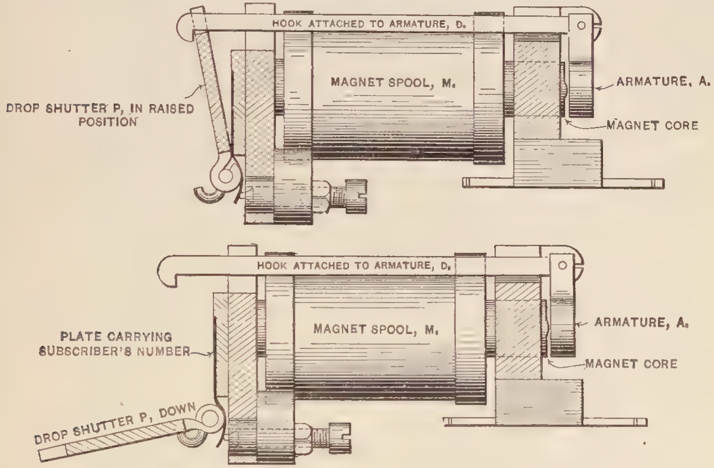
HOOK ATTACHED TO ARMATURE, D.
MAGNET SPOOL, M.
ARMATURE, A.
DROP SHUTTER P, IN RAISED POSITION
MAGNET CORE
HOOK ATTACHED TO ARMATURE, D.
MAGNET SPOOL, M.
ARMATURE, A.
PLATE CARRYING SUBSCRIBER'S NUMBER
MAGNET CORE
DROP SHUTTER P, DOWN

FIG. 255. — Electromagnet and Shutter for Telephone Switchboard.

A "spring jack" is an arrangement by means of which an electrical connection may be made by inserting a metallic plug into a hole so that it touches a spring which is in electrical connection with the circuit. Figure 256 illustrates a spring jack.

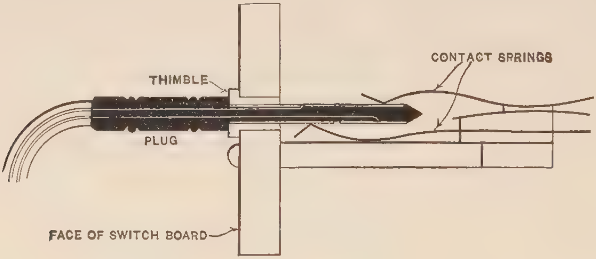

FIG. 256. — Telephone Spring Jack.

When a subscriber **Calls** by working his magneto, the fact is indicated at the exchange by the fall of the **Drop** belonging to his line. The exchange operator inserts in this subscriber's spring jack a plug which is at one end of a conducting cord, and at the same time moves a switch which connects her telephone to his line. She inquires what connection is desired, makes it by inserting the plug at the other end of the conducting cord in the spring jack belonging to the line of the desired subscriber, and calls him by pushing a button which causes his telephone bell to ring. This completes the operator's duty in connecting the two subscribers. When the subscribers have finished talking, one of them turns his magneto crank, which causes a special "drop" to fall in the exchange and calls the operator's attention to the fact that the lines may be disconnected.

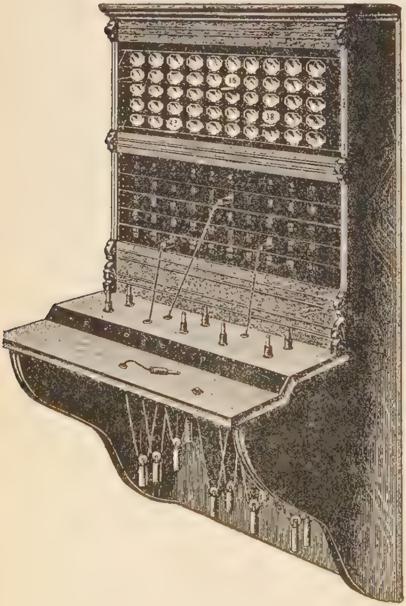

FIG. 257. — Simple Form of Switchboard for Small Exchanges.

Boards of this general type are used

in small exchanges. On large boards, tiny electric lamps are used for signals instead of "drops." A storage battery is installed in the exchange for operating them. Lifting a subscriber's telephone receiver from its hook completes a circuit through the central battery so that his line signal lamp on the board is lighted, and no generator is needed at the subscriber's station. The same central battery supplies current for the subscriber's transmitter.

**315. Multiple Boards.** — As one operator can take care of the calls from only a limited number of subscribers (50 to 100 is the usual number per operator), a great many boards of the kind described would be required in the larger exchanges, and much difficulty and waste of time would be experienced in making connections between the line of a subscriber connected to one board and the line of a subscriber connected to another board in another part of the room. Hence, what are known as **Multiple Switchboards** are used in exchanges having many subscribers.

The multiple board with its numerous details can be explained here only in the briefest outline. The principle upon which it is based is to divide the total number of subscribers' lines into sets, each of which is brought to a different section of the switchboard where the lines belonging to the set may be looked after by an operator. The lines are connected to a drop and a spring jack in their proper sections, so that the operator may communicate with the subscribers by means of her telephone set. In addition to entering its own section through a drop and spring jack, every subscriber's line is also connected to a spring jack in every other section. Consequently each operator attends to the calls of a limited number of subscribers whose lines are connected to drops in her section, and since all other lines have spring jacks in her section she can connect any of her subscribers' lines to the line of any other subscriber which enters the exchange.

Figure 258 shows the principle of the multiple board. The dots marked "local jacks" in each section represent the spring jacks belonging to the lines which are looked after by the operator at the section. The drops, the keys for ringing up subscribers, the operator's telephone set, etc., are omitted from the figure for the sake of simplicity. The dots marked "ordinary jacks" represent the multiple spring jacks, by means of which the operator may connect any one of her subscribers with any other that is connected with the exchange. It will be seen, for instance, that subscribers' lines, Numbers 1, 2, and 3, enter the local jacks of section Number 1, but they also enter the ordinary jacks of the other sections. If an operator in the second section wishes to connect one of her wires, say Number 6, with one of those belonging to the first section, say Number 3, she is able to do so at once on her part of the board, as shown in the figure.

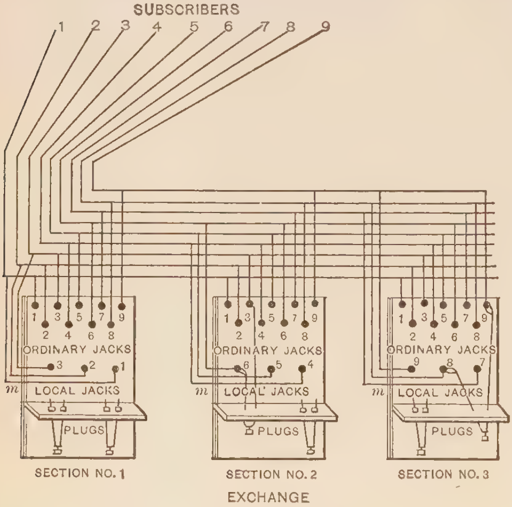

FIG. 258. — Diagram of Multiple Switchboard.

An ingenious arrangement by which the operator can tell when a line is in use, prevents switching three subscribers together. Exchanges with multiple switchboards have been planned to give telephone service to the enormous number of ten thousand subscribers from one board, but the telephone service has never yet risen in any place to such magnitude that any exchange has reached the number of ten thousand subscribers, since it is customary to divide the service among sub-exchanges. This is done in the large cities for the purpose of economizing in the construction of lines, and several sub-exchanges are therefore located to serve the districts outside of the area immediately around the main exchange. This practice causes the number of subscribers' lines attached to any one exchange to be smaller than might otherwise be expected.

**316. Ground Returns.** — The earth has in the past been very commonly used as one-half of telephone circuits, so that only one wire need be used to connect an instrument with the exchange. The ground terminals of the instruments are then connected by wire to gas or water pipes, or to iron bars driven into the ground. The telephone receiver is such an exceedingly delicate instrument that outside currents are likely to affect its operation when the **Ground Return** is used, and important lines are nowadays constructed with a complete **Metallic Circuit**; that is, with metal wires for both the outgoing and incoming part of the line. A special transmitter, called the *long-distance transmitter*, is generally used with metallic circuits. This transmitter, which is shown in Figure 259, is a microphone transmitter in which the loose contact between a bit of platinum and a carbon button is replaced by a short tube faced with metal or carbon buttons and containing powdered carbon. The carbon "granules" contained in the tube are so arranged that the vibrations of the diaphragm vary the pressure with which they lie against each other, and the total resistance of the tube passes through wide variations. This transmitter is, therefore, very powerful, and is especially useful in connection with circuits of great length.

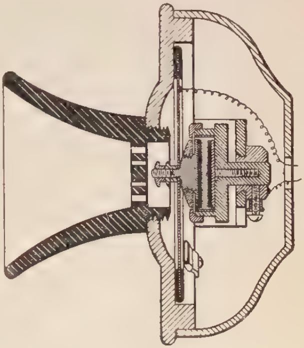

FIG. 259. — Cross Section of a Long-distance Telephone Transmitter.

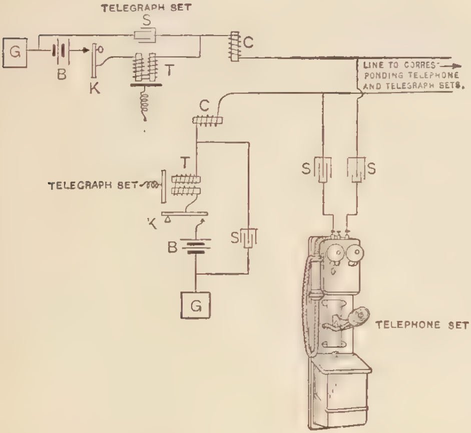

FIG. 260. — Diagram of Circuits for Telegraphing and Telephoning simultaneously.

**317. Simultaneous Telephony and Telegraphy.** — The rapid variations of the telephone current, which are caused by the vibrations of the diaphragm under the influence of the voice waves, transmit themselves by induction through a condenser, while the slow make and break signals of the Morse telegraph do not. Utilizing these characteristics makes it possible to adapt a circuit for telephoning and telegraphing at the same time. This double use of telephone conductors is extensively adopted on the long-distance telephone lines in this country.

A diagrammatic sketch illustrating one arrangement of the apparatus is shown in Figure 260. The rapidly varying telephone currents are effectively choked back by the high self-induction of the telegraph instruments, so that they do not dribble off through them; and the condensers in circuit with the telephones keep the telegraph signals from interfering with the talking currents.

**318. Wiring Bell Circuits.** — The wires used for electric bell circuits have a very different insulation from that of electric light wires.[1] The wire commonly used inside of buildings for bell circuits is called "annunciator wire." It is a copper wire with an insulation consisting of two heavy cotton wrappings, wound in opposite directions, and thoroughly waxed and paraffined. These wires are made of various sizes and are frequently striped in different colors. Sometimes what is known as "office wire" is used for telephone and messenger call connections. The insulation of "office wire" ordinarily consists of two braidings of cotton which are well soaked in paraffine.

While no danger can arise from the use of these poorly insulated wires for such circuits, provided they are not in a position to come in contact with electric light wires, yet a great deal of inconvenience is caused by their unsatisfactory and leaky character. This is the condition of numberless electric bell circuits in houses all over the country where the front door bells fail to ring when the buttons are pushed. The trouble is caused by the current leaking from poorly insulated wires where they come in contact with dampness or at some point where they are both placed under one metal staple, and the difficulty in a great majority of the cases would never have appeared had wire with good rubber insulation been used. As No. 18 B. & S. wire is usually used for the bell circuits, the extra cost caused by using rubber-covered or "weather proof" wire is not very great, while the inconvenience avoided by its use may be considerable.

It must not be assumed, however, that all the troubles to which bell circuits and similar circuits are heir arise from poor insulation. Battery zincs become used up or the water evaporates, and the battery may not work on that account. The mechanism of bells and push buttons is very simple and not likely to get out of order, but trouble may occur even in them. The contact in a push button gradually becomes corroded, and then when the button is pushed it does not complete the circuit. This fault is easily remedied by taking the cover off the button and scraping the contact points.

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[1] See Chapter XX.

Figure 261 is a diagram which shows two arrangements for electric bell circuits. The battery consists of one or two open circuit cells. These are connected in series with the bell and push button by wires which may run within the walls of a house. When the button is pushed, it closes the circuit and the bell rings. When the button is not being pushed, the circuit should be open and the battery at rest.

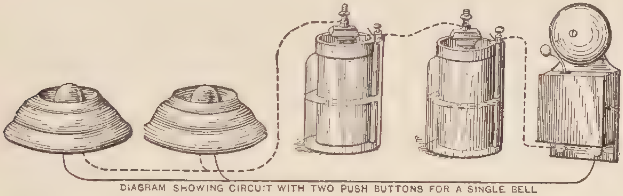

DIAGRAM SHOWING CIRCUIT WITH TWO PUSH BUTTONS FOR A SINGLE BELL

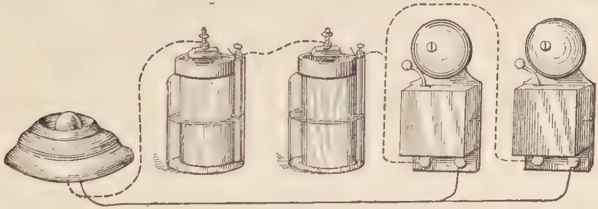

DIAGRAM SHOWING CIRCUIT FOR RINGING TWO BELLS FROM ONE PUSH BUTTON

FIG. 261. — Diagram of Electric Bell Circuits.

If a leak occurs from wire to wire, the battery remains in action all the time, and the depolarizer[1] (if the battery has one) soon becomes exhausted and the battery becomes polarized or "run down." The bell then fails to ring when the button is pushed. If the battery has no depolarizer, the process of running down occurs in exactly the same way, but it is more rapid.

[1] Article 41.

When one bell is operated from one push button, the circuit is exactly the same as though one push button were removed from Figure 261. The bell service in most houses is performed by several circuits, each of which includes a bell, *B*, and a push button, *A*; but one battery is used in common for all circuits. This is illustrated in Figure 262, from which it may be seen that the bell circuits are connected in parallel to the common battery, *C*.

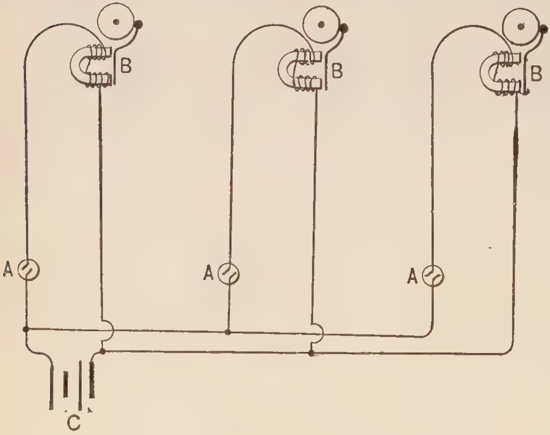

FIG. 262. — Diagram of Household Bell Circuit.

**319. Electric Bells.** — The mechanism of the ordinary vibrating electric bell consists of a stationary electromagnet, *E* (Figure 263), with a vibrating armature, *A*, which is fastened at one end to a spring hinge, *S*, and carries at the other end the bell clapper, *H*. When an electric current is passed through the electromagnet of a bell, the armature is attracted and moves forward so that the clapper strikes the gong. At the same time the electric circuit is broken by a spring contact, *C*, at the back of the armature, the magnet loses its magnetism, and the armature flies back to its original position. When the armature flies back, the circuit is again completed at the spring contact, *C*, the armature again flies forward, the clapper again strikes the gong, and the whole process is rapidly repeated over and over again as

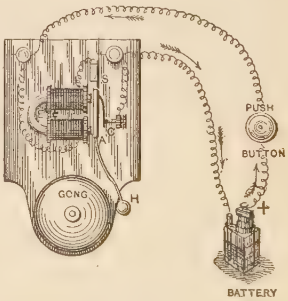

FIG. 263. — Electric Bell with Battery and Push Button.

long as the electric circuit is complete at the push button. The back-and-forth motion of the armature causes the clapper to strike a succession of blows on the gong, and thus causes the ringing of the bell. When a bell gets out of order, the trouble is usually to be found in the spring contact, which may be dirty or out of adjustment, or the electromagnets may be short-circuited.

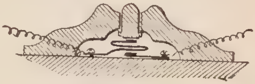

FIG. 264. — Cross Section of Ordinary Push Button.

Figure 264 is a diagram of a push button, the simplicity of which is to be seen at a glance.

Sometimes it is not desirable to have an electric bell ring continuously while the push button is depressed, and in that case the spring contact, *S*, is omitted, and the conducting wires are connected directly to the electromagnet. Such a bell makes a single stroke for each push of the button, and it is therefore often called a "single-stroke bell."

It is an interesting fact that the use of electric bells was the first application of electricity to household purposes, and that the principle of the electric bell was first made use of by Professor Joseph Henry about 1830.

## QUESTIONS

38. What do the words "telegraph" and "telephone" mean?
39. When was the first speaking telephone invented? By whom?
40. Describe a Bell telephone.
41. What causes sounds to be heard in one Bell telephone which are similar to those spoken to a second telephone properly connected with the first?
42. Is a permanent magnet essential to the working of a Bell telephone?
43. Why is the Bell telephone not commonly used as a transmitter?
44. How may the resistance of loose carbon contacts be varied?
45. What is the principle of the Blake transmitter?
46. Why does a Bell receiver properly placed in circuit reproduce words spoken into a Blake transmitter?
47. Who discovered the properties of loose carbon contacts?
48. What is a microphone?
49. How does a Blake transmitter differ from an ordinary microphone?
50. Why is a transformer or induction coil used with a carbon transmitter?
51. What apparatus is placed in telephone sets?
52. What is the purpose of each part of the set?
53. Describe the circuits of a telephone set.

54. How are the circuits switched on to and off the line?

55. What is a central telephone exchange?

56. What is the purpose of a telephone switchboard?

57. What are the "drops" on a telephone switchboard for? How do they work?

58. How does a multiple switchboard work?

59. Why are metallic circuits preferable for telephone work?

60. What is the essential difference between a long distance and a Blake transmitter?

61. How may telephony and telegraphy be carried on over the same wires?

62. How is an electric bell made?

63. How does an electric bell work?

64. When did Henry make and use the first electric bell?

65. How are bells connected up for service?

66. What kinds of wire are used in bell circuits?

67. Why must bell wires be well insulated?

68. What troubles are apt to appear in bell circuits?

# CHAPTER XX

## LINE CONSTRUCTION AND THE ELECTRIC DISTRIBUTION AND TRANSMISSION OF POWER

**320. Line Material.** — A large proportion of the electric light and power, telegraph and telephone lines in the United States are supported on the wooden poles which are so common in city streets and along railroads and highways. Usually these poles are made of white cedar or chestnut, though in some parts of the country pine, cypress, and tamarack, or other woods, are used. The poles differ in length from 25 feet to as much as 100 feet, and in diameter at the upper end from 4 or 5 inches to 8 or 10 inches. The sizes which are most commonly used are from 25 to 60 feet long and from 6 to 8 inches in diameter at the top. These are set in holes dug in the ground to a depth which depends upon the length of the poles and the importance of the lines which they carry, but which is approximately equal to one-sixth of the length of each pole. The wires which are supported by the poles are usually tied fast to glass **Insulators**, which are screwed on oak or locust **Pins** (Fig. 265), fastened to pine **Cross Arms.** The arms are usually $3\frac{1}{4} \times 4\frac{1}{4}$ inches, and as long as required. Figure 266 shows the general arrangement of a line of 18 wires. The cross arms fit into notches called **Gains**, which are cut in the sides of the poles, and they are then fastened in place by means of lag screws or bolts.

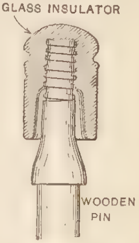

FIG. 265. — Wood Pin with "Pony" Glass Telephone Insulator, about one-seventh size.

Poles are commonly erected with the cross arms facing each other on alternate pairs of poles (Fig. 267). If they are set in this manner, the arms are not likely to be pulled off; but when all the arms face in one direction, it is possible for all of them to be pulled off, one after another, on account of the breaking of a pole or of one of the arms. Figure 268 shows the top of a pole arranged to carry 50 long-distance telephone wires. The numbers marked on the figure show the dimensions. In this figure the cross arms are shown braced with iron braces. These are ordinarily used when the arms are intended to carry heavy or particularly important wires. The braces are quite commonly used in cities, but are omitted in country telegraph lines. Iron or steel wires are very commonly used for telegraph and telephone lines, but copper wires are used on the most important long-distance lines.

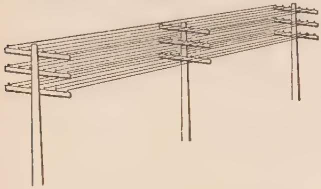

FIG. 266. — Illustration of a Short Portion of Pole Line carrying Eighteen Telegraph Wires.

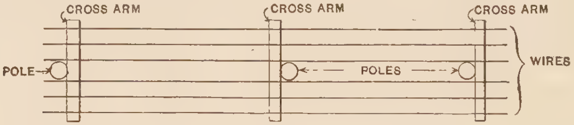

FIG. 267. — View of Pole Line, with "6 Pin Cross Arms," from above.

As a general rule electric light and power lines carry fewer but much heavier wires than telephone or telegraph lines. The sizes of the wires depend upon the current transmitted over them, their length, and the drop of pressure which is permitted to occur in them. The dimensions are determined by methods to be explained.[1] Electric light and power wires are always of copper or aluminum of the highest obtainable conductivity, and they ordinarily vary in size from No. 8 to No. 0000 B. & S. gauge, or from about $\frac{1}{8}$ of an inch in diameter to nearly $\frac{1}{2}$ of an inch in diameter. The former is the smallest wire of soft copper which can be depended upon not

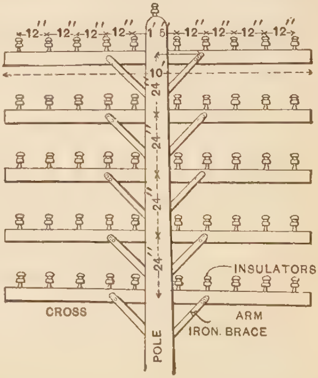

FIG. 268. — Cross Arms, Pins, and Insulators on Long-distance Telephone Pole arranged for Fifty Wires.

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[1] Article 329. Also Chapter VII.

to break from mechanical strains caused by its swaying in the wind, other wires falling upon it, etc., while the latter is the largest solid wire which can be conveniently handled; and if larger conductors are used, they are made out of strands of smaller wires. Where a number of large wires are run on the same pole line, extra heavy poles and cross arms are used.

**321. Wire Insulation.** — The wires used upon overhead telegraph and telephone lines are not covered with insulation, and the same is true of some low-pressure electric light lines. For instance, the overhead wires used to distribute current for incandescent lighting by the ordinary three-wire system were formerly almost always bare, and the glass bells at the points of support were depended on to give a satisfactory insulation. This is perfectly safe when the pressure is as low as in the ordinary three-wire system, where the pressure between the positive and negative wires is seldom higher than 260 volts. When the pressure used on overhead lines is higher than 300 volts, it is usual to use insulated wires within the limits of cities and towns. The insulation consists of a continuous braided cotton covering of two or three thicknesses, which is thoroughly soaked with some insulating compound. As the insulation is supposed to be partially waterproof, such wire is often called **Weatherproof Wire.** The insulating compound is almost always black.

Black weather-proof wire is used for the overhead lines of power plants which distribute current to motors at a pressure of 500 volts, for the overhead lines of alternating current electric light plants, which use a pressure of 1000 or 2000 volts, for the feeders of electric railway plants, arc-light wires, etc. It has become an almost universal custom in this country to use No. 6 B. & S. gauge weather-proof wires for overhead arc-light lines. As the arc current seldom exceeds 10 amperes, the loss of pressure in a No. 6 wire several miles in length is not very great, and it is a convenient and economical size to use.

The circuits for electric lighting and power are always complete wire circuits, as the use of the ground for returning large currents is sure to cause difficulties from the uncertain and comparatively large resistance of ground plates, and a *grounded electric light circuit always introduces a risk of fire in each house that it enters.* For the latter reason fire insurance men or **Underwriters** refuse to approve the use of a ground return for the distribution of electric light and power where the wires enter buildings insured by them.

**322. Erection of Poles.** — In erecting the poles, care must be taken that they are set in straight lines as much as possible. If curves or corners are turned, the poles at the turn must be **Braced** or **Guyed** to prevent their being pulled over by the strain of the wires. Figure 269 shows a pole which is braced against a side strain by means of a timber brace, and Figure 270 shows poles held against side strains by wire **Guys** which are fastened in two ways. When the guy crosses a street or other passageway, it is not uncommon to make the post or **Stub** to which the guy is attached eight or ten feet high. The latter figure shows the poles somewhat tipped or inclined. This is an additional safeguard against the poles being pulled over by the strain of the wires. In cities the poles are ordinarily shaved all over with a draw knife before being set, and they are then painted, but in the country this refinement is not generally considered to be necessary. The distance between poles which carry telegraph and telephone wires varies from about 120 feet to 300 feet, or the number of poles to the mile varies from 45 to 18. Only in the case of important lines carrying many wires are the shorter distances between poles used, and the average number of poles used for lines running through the country is from 20 to 30 per mile. Poles which carry electric light wires are generally placed at shorter distances apart, these distances varying from 100 feet to 150 feet, depending upon the weight of the individual wires and the importance of the lines.

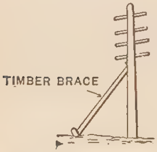

FIG. 269. — Corner Pole braced against Side Strain.

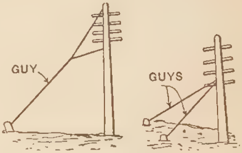

FIG. 270. — Corner Poles held against Side Strain by Wire Guys.

**323. Stringing Wires.** — Various methods are used in stringing wires. One of the commonest ways is to unreel a certain length of the wire out on the ground, after which it is carried to its place on the insulators, drawn up tight, and tied fast by linemen who climb the poles by means of spurs; and then the operation is repeated on another length. In another method, the set of wires may be drawn over the cross arms from a fixed reel

Wire which is intended for use on pole lines is usually furnished in coils which may be laid on a hand reel or a reel mounted upon a wagon. When a considerable length of wire has been laid on the cross arms, a block and tackle is attached to its end and it is stretched up tight. While the wire is held tight, it is tied by linemen to the insulator upon which it is placed at each cross arm. The tie is usually made of wire like that in the lines, but it is often somewhat smaller in size. The line wire is laid in the groove of an insulator, and one end of the tie wire is twisted tightly around it close to the insulator. The tie wire is then carried around the groove in the insulator, and its other end is twisted tightly around the line wire close to the insulator. The appearance of the line wire and loop of tie wire with the insulator removed, is shown in Figure 271.

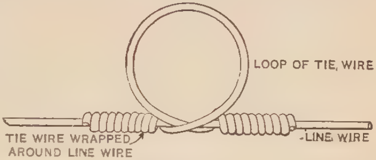

FIG. 271. — Illustration of Loop of Tie Wire with its Ends wrapped tightly around Line Wire.

**324. Wire Joints.** — Wire is furnished from the wire mills in coils which contain lengths varying from a few hundred feet to a half mile or more. A great many joints are therefore necessary in a long line. The commonest form of joint used in this country is that known as the Western Union or twist joint, which is shown in Figure 272. The figure shows the way a twist joint appears when made of iron wire of medium size and also when made of small copper wire.

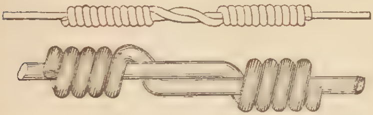

FIG. 272. — Illustrations of "Western Union Joints" in Small and Medium-size Wires.

In electric light and power lines these joints are always soldered, in order that their electrical conductivity may be as great as possible, and that the wires at the joint may not be corroded by the effect of gases which are in the air. The soldering is done by dipping the twisted joint into a pot of melted solder, or, if the wire is large, by pouring solder on the joint from a ladle. Many specially arranged "sleeve" joints are also used. Here the wires are slipped from opposite directions into the sleeve, and the sleeve with the wires is thoroughly twisted, or the ends of the wire are pushed beyond the ends of the sleeve and are turned up to avoid their pulling out, and the whole joint may then be filled with solder.

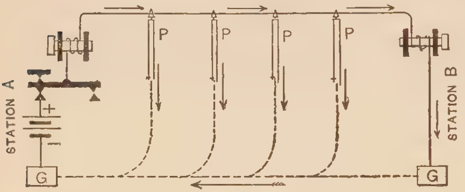

FIG. 273. — Illustration of the Effect of Poor Insulation.

**325. Insulators.** — The insulation of all kinds of electric lines is a matter of much importance. The effect of poor insulation is illustrated in Figure 273, where *A* and *B* are two telegraph stations connected by a wire strung upon the poles marked *P, P, P, P.* The electrical circuit through the stations is completed by a ground return through the ground plates marked *G, G.* All the battery is supposed to be located at station *A.* If the wire is not well insulated at each point where it is supported at the poles, an appreciable portion of the current leaks out of the line into the earth without having passed through the distant station. Each point of leakage gives a branch circuit; and if the line is long, so that many such branch circuits are in parallel, the total leakage may be so great that sufficient current does not reach station *B* to work its relay when signals are made by means of the key at station *A.* The actual proportion of the current which escapes by leakage depends upon the ratio which the line resistance bears to the combined resistance of all the leakage paths taken in parallel.[1] Where a **Metallic Circuit** (that is, where wires are used for both outgoing and return conductors) is used, the leakage paths reach from one wire to the other instead of from one conductor to the earth.

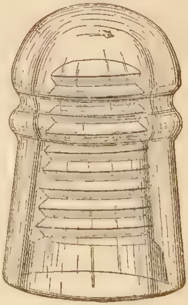

FIG. 274. — Glass Telegraph Insulator. About one-third size.

To make the resistance of the leakage paths as great as possible, the insulators to which the line and wire are attached at the poles are commonly made of glass in the form of bells (Fig. 274), which may be screwed on the wooden pins in the cross arms. These insulators are made in various slightly different forms and sizes. That shown in Figure 274 is suitable for small wires such as are used in telegraphy and telephony. That shown in Figure 275 is suitable for the larger wires used in electric light lines.

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[1] Article 103.

Glass is an excellent insulator when it is dry,[1] but in damp weather its surface becomes covered with a thin layer or film of water. This film of water makes a path through which, at every insulator, a small portion of current may leak from the wire to the wooden supporting pin, and thence over the damp wood of the cross arm and pole to the ground, or to some other wire. Water is a comparatively poor conductor, and the quantity of current which escapes at each insulator is very small, but the total loss at all the insulators, on a line several hundred miles long, may be a very serious matter. As the leakage at each insulator is along the film of water which covers the surface of the glass, the effective insulation is increased by increasing the length of the path over which the current must pass on the insulator's surface. This is done by adding a second "petticoat" or bell to the glass, as shown in Figure 275.

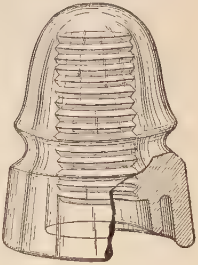

FIG. 275. — Glass Insulator with Double Petticoat. About one-third size.

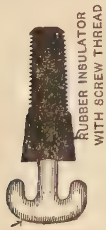

FIG. 270. — Rubber Hook Insulator. About one-fifth size.

Rubber hook insulators (Fig. 276) which may be screwed into the bottoms of cross arms or in other similar positions are sometimes used for special work. In Europe, porcelain bell insulators which are quite similar in shape to the American glass insulators, are used. The dense white porcelain of which these insulators are made is in some respects better than glass for the purpose, but it is more expensive. Large porcelain insulators are also being used in this country for some of the lines over which power is transmitted by the electric current at high pressures. Sometimes these have triple petticoats.

Where telegraph or telephone lines run inside of buildings, it is usual to use copper wire of a small size which is insulated by a braided or wrapped covering of cotton thread thoroughly soaked with paraffine; and rubber insulated wire is used for electric lighting and power lines when they run inside of buildings. Where single lines need support, as in passing from the poles to a building, it is usual to use an oak bracket (Fig. 277) with a glass insulator, or a porcelain knob (Fig. 278) fastened at some convenient point.

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[1] Article 7.

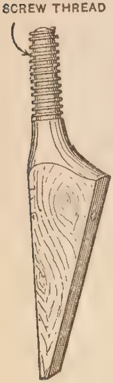

FIG. 277. — Oak Bracket with Screw Thread for Glass Insulator.

**326. Underground Wires.** — In large cities, electric conductors are often put underground, and in some places they are run over housetops. When electric wires are placed underground, they must be continuously insulated by some material which is sufficiently flexible to permit the wires to be easily handled. For power and lighting wires this insulation often consists of a thickness of a vulcanized rubber compound which has been placed on the wire under hydraulic pressure, but the covering for some cables is made by closely wrapping the conductor with strips of paper which have been soaked in an insulating compound so as to make it quite soft and flexible. The thickness of this paper wrapping is made about the same as that of rubber insulation, and over it is put a lead sheathing which is similar to the sheathing of rubber insulated cables. A third style of insulation consists of a thick braiding or wrapping made up of several layers of cotton or jute which is soaked in an insulating compound quite similar to that used for weather-proof wires. This is also covered with a lead sheathing. The latter cables are often said to have *fibrous* insulations on account of the character of the materials used. As fibrous material will rapidly absorb moisture and its insulating qualities are then ruined, it is necessary that the lead sheathing shall contain no holes, however small, and the ends of the cables must be carefully protected from moisture. The protection of rubber insulation is not so important, but moisture may even here have a serious effect, and the most careful handling of the cables is advisable.

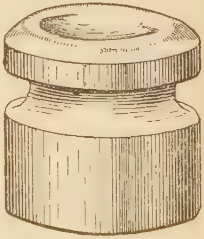

FIG. 278. — Porcelain Knob Insulator.

In the case of telephone wires it is particularly important that their electrostatic capacity be the smallest that is possible, on account of the delicacy of the telephone current, and crinkled paper is often used for their insulation.[1] When a fibrous insulation such as paper is used, it is necessary to protect it from absorbing moisture, and a lead covering over the insulation is, therefore, used. In fact, the lead covering is generally used with rubber covered wires also, in order that the rubber may be properly protected from mechanical injury and from the injurious action on its insulating qualities of gases or liquids which may come in contact with it when underground.

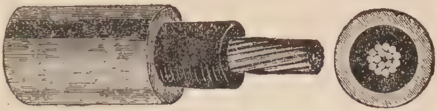

FIG. 279. — Electric Light Cable with a Single Conductor.

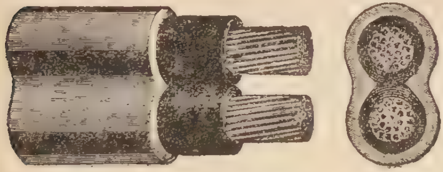

FIG. 280. — Duplex (Twin-conductor) Electric Light Cable.

Before the lead covering is put on the insulated wires, a number of them are usually "laid up" or bunched into a **Cable**, for telephone or telegraph work; while a single wire, or at most three or four wires, are used for power and lighting, and the lead is put around the whole. Figure 279 shows a single underground conductor, and Figure 280 a "duplex" cable; that is, one with two conductors, and the lead put around both insulated conductors. The lead may be put on by pulling the cabled conductors into a lead pipe, or by making a pipe around the conductors by squeezing melted lead over them by means of a hydraulic press. The end of a telegraph cable is shown in Figure 281.

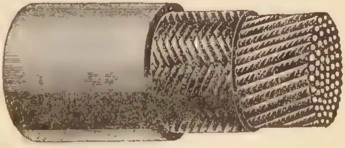

FIG. 281. — Illustration of Sixty-conductor Telegraph Cable, with Conductors exposed to View by stripping off the Lead and Braiding at one End. Reduced size.

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[1] Article 190.

**327. Underground Conduits.** — Underground cables are not usually buried directly in the ground, but are placed in what are known as **Electric Conduits.** These consist of pipes or **Ducts** made of iron, terra cotta or vitrified clay, cement, wood, and sometimes other materials. The ducts are sometimes laid singly, but they are usually laid in sets surrounded by concrete, as shown in Figure 282, which is an end view of a conduit containing twelve ducts. The ducts are commonly circular in cross section and three or four inches in diameter, though ducts of rectangular cross sections and of other dimensions are often used.

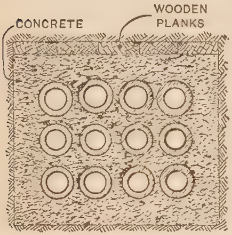

FIG. 282. — End View of Conduit containing Twelve Ducts.

In order that cables may be placed in the conduits, arrangements for getting at the ducts must be made. This is done by building cable **Manholes** at intervals along the conduit. These are usually brick vaults, six or seven feet deep and several feet in diameter, which are covered at the street surface by cast iron covers. Sections of the conduit terminate on opposite sides of the manholes, as shown in Figure 283. The manholes are placed at intervals of about three hundred feet in straight parts of a conduit and also at turns.

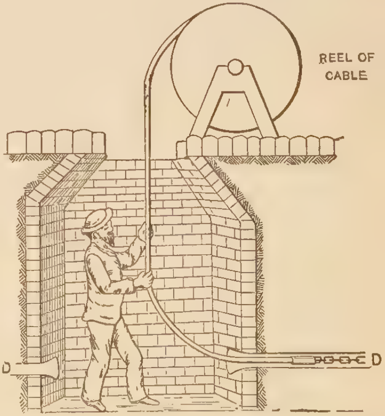

FIG. 283. — Large Cable Manhole, showing Cable fed from Reel into Duct through which it is being pulled. *DD*, ducts.

When a conduit with its manholes is completed, the cables are drawn into the ducts, one section at a time. The sections of each cable must be jointed together in the manholes. To do this, the conductors are first jointed in the usual manner, as already described,[1] and their joints are separately insulated. Finally, a short piece of lead pipe is placed over the bunch of joints and is soldered at both ends to the lead covering by a plumber's "wiped joint." This makes the joint moisture proof if the work is properly done. Making cable joints requires the greatest care to avoid the entrance of moisture into the cable, and it is always necessary to handle open cable ends with extreme caution. The ends should always remain sealed except when work is to be done on them.

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[1] Article 324.

When a cable is to be pulled into a duct, a strong rope must first be passed through the duct so that it may be used in drawing through the cable. Several plans are in use for getting the rope through. A light runner which nearly fills the end of the duct may be attached to a cord, and the runner, with the cord trailing after it, may be sucked or blown through the duct by a mechanical blower. The cord may then serve to draw the rope after it. But the commonest plan for getting the rope through a duct is called "rodding" the duct. A large number of rods made of hickory, bamboo, or the like, about a yard long, are provided with metal ferrules and couplings at each end. One of these rods is slipped into one end of a duct by a man standing in a manhole and another rod is then coupled to the end of the first. The second rod is then pushed into the duct (while it pushes the first before it), and a third rod is coupled to the end of the second. This process is continued until the first rod is pushed through the duct into the next manhole. A rope is then attached to the end rod, the rods are withdrawn (while they are uncoupled, one by one), and the rope is drawn into the duct after the rods. When the last rod is withdrawn, the rope lies extended from end to end of the duct and may be used to draw in a cable.

A "leading-in wire" may be put in the ducts when they are laid, and and it may then be used to draw in the rope; but this is not usually considered desirable or convenient.

A second method of laying underground conductors for the distribution of electric current is often called the *solid* or *built-in* system, because the insulated conductors with their protecting conduit are laid in the ground together. In this case, if any harm comes to either the conductor or its insulation, the street must be dug up at the place of "trouble" before repairs can be made, and for this reason new plants do not often now install such systems. With the "drawing-in" system, repairs may be made by simply pulling out that section of cable between two manholes which contains the injury, and replacing it with a piece of good cable.

The "built-in" system has been used for low pressure distribution of electric current, and for this purpose gives excellent satisfaction. Nearly all the great electric illuminating companies in our large cities which use the three-wire system have older conductors laid in this manner. For high pressure distribution, the "built-in" system of underground conductors is not as satisfactory as the "drawing-in" system.

The most commonly used arrangement of the "built-in" system is that known as "Edison tubing." This was introduced nearly a score of years ago, and was used in its original form in the laying of the conductors connected with the old Pearl Street Central Station in New York City, the first great central station for the general distribution of the electric current. Edison tubing was the earliest, and for many years the only scheme, in which the details of a general underground system for distributing electric current were satisfactorily worked out.

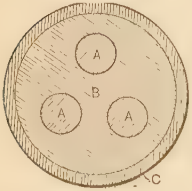

Fig. 284. — Sectional View of Edison Tube with Three Equal Conductors.

On account of the experience gained in laying the conductors for the various large Edison electric illuminating companies, the system of tubing has been considerably changed since its first introduction. As the tubes are now made, they usually contain three copper rods — the positive, negative, and neutral conductors of the three-wire system. These rods, which are somewhat over twenty feet long, are each wound with a spiral of manila rope, and are then laid side by side but separated from each other by the ropes. Another spiral of rope is wound around the bunch to hold the conductors firmly together. The bunch of three conductors is placed in an iron pipe twenty feet long, in such a way that the copper rods stick out a few inches at each end. One end of the pipe or tube is then connected to a pump by means of which a vacuum is created in the tube, and, finally, hot, black insulating compound is pumped into the tube until all the open space inside of it is filled. The insulating compound is of a bituminous nature and hardens when it is permitted to cool. Figure 284 shows a cross section of a "tube" in which *A*, *A*, *A* are the copper conductors, *C* is the iron pipe, and *B* is the insulating compound. Figure 285 shows a length of the completed tubing, showing the form in which it is delivered from the factory to be laid in the ground. For the purpose of laying the tubes, a trench is dug, and the twenty-feet lengths are laid down end to end. The conductors in successive tubes are joined by means of flexible copper connectors (Fig. 286) having solid copper heads with holes which slip over the ends of the rods where they are soldered fast. Ball-like caps are bolted fast to the tube ends, and over these is bolted a split *coupling box* which covers the joint. In the top of this coupling box is a hole through which hot insulating compound may be poured when the joint is completed, and the hole is then covered with an iron cap.

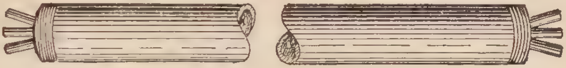

FIG. 285. — Illustration of Edison Tube.

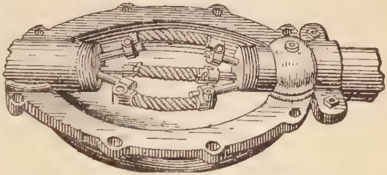

FIG. 286. — Coupling Box for Edison Tubes, showing Flexible Connectors.

The arrangement here described is very satisfactory, since it offers an electric company the same ease as a gas company or a water company in making connections to houses. A branch to a house, or **Service Connection**, as it is called, may be connected to the main conductors at any coupling box by simply changing the plain box to a T-shaped box and running a branch into the house. With "drawn-in" systems, access to the conductors can easily be obtained only at the manholes, and house-to-house distribution cannot be so conveniently made.

Several different arrangements of "built-in" conductors have been used in England, France, and Germany. One of these consists of a simple brick, concrete, or cast-iron trench, or culvert, in which the copper rods or bars used for conductors are placed on porcelain insulators. One of the most remarkable arrangements of the "built-in" system is that constructed some years ago in London to conduct electric current by the two-wire system from the noted Deptford Central Station into the heart of the city. The conductors in this case are enclosed in an iron pipe, as are the conductors in the Edison system, but the conductors themselves are copper tubes placed one inside of the other instead of being rods placed side by side. The space between the conductors is filled with insulation, which consists of brown paper soaked in an insulating compound. The same kind of insulation is also placed between the outer conductor and the iron protecting pipe. This conducting system was designed and laid down to transmit current at the then enormous and unusual pressure of 10,000 volts, and it served its purpose very well. As the tube could not be made in lengths much greater than twenty feet, jointing the lengths together was a matter of much difficulty on account of the *concentric* arrangement of the conductors.

**328. Arrangement of Distributing Systems.** — In order that the electrical pressure may be kept the same at all points on a system of electric or power conductors which cover a large district, the conductors must be divided into **Feeders** and **Mains**. The mains consist of the conductors to which lamps or motors are directly connected. These are carried all through the streets of the district in which current is to be supplied, and they are often joined into a network by means of fuses located in manholes or **Junction Boxes** at street corners. The current is supplied to the mains at certain central points called **Feeding Points** by means of feeders which run directly to the feeding points from the central station where the current is generated. Figure 287 is a diagram representing the arrangement of feeders and mains. The points marked 1, 2, 3, 4, are the feeding points, and *A*, *B*, *C*, *D*, are houses to which current is supplied through service connections. The figure shows three wires in each main and feeder, as is required in a three-wire system. By carefully calculating the resistance of each main and feeder before the system is constructed it is possible to get a very uniform pressure over

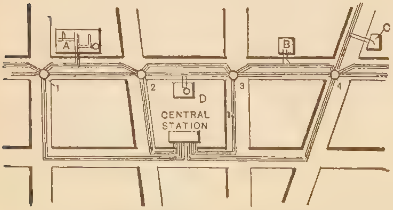

FIG. 287. — Illustration of the Arrangement of the Feeders and Mains in the Conducting Network of an Electric Light Plant.

the whole distributing system. In order that the dynamo men may regulate the pressure of the dynamos in the central station so as to keep the pressure uniform at the feeding points, it is necessary to have voltmeters, or pressure indicators, in the dynamo room, which show the pressure at the feeding points. For this purpose wires called **Pressure Wires** are run from the feeding points to the voltmeters in the dynamo room. A somewhat similar network of pipes is sometimes used in the distribution of gas and water in large cities.

**329. Determination of Wire Sizes.** — The sizes of the wire used in electric light and power systems are usually determined with a view to preventing an excessive **Drop** in pressure, caused by the current which flows along it,[1] with its corresponding loss of energy in the conductors. Copper wire is ordinarily used, and the resistance of a commercial wire which has a cross section of one circular mil and a length of one foot (that is, one mil-foot) is about 10.5 ohms at ordinary temperatures.[2] The *resistance of any copper wire is, therefore, equal to 10.5 times its length in feet divided by its cross section in circular mils*, since the resistances of conductors are proportional directly to their lengths and inversely to their cross sections.[3]

As a formula which is easy to remember, the statement in italics may be written[4]

$$R = \frac{10.5\ L}{C.M.}$$

Now the drop in pressure in a line of resistance $R$, when current $C$ flows through it, is[5]

$$V = R \times C,$$

and therefore,

$$V = \frac{10.5 \times L \times C}{C.M.},$$

from which it is at once to be seen that

$$C.M. = \frac{10.5 \times L \times C}{V}.$$

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[1] Articles 107 and 261.

[2] Article 100.

[3] Article 101.

[4] Tables giving the sizes of wires for electric lighting nearly always have a column which shows the cross sections in circular mils.

[5] Article 92.

The last formula shows that *the wire which conveys the current from a dynamo to lamps or motors must have the number of Circular Mils in its cross section which is equal to the specific resistance* (for copper 10.5) *times the total Length of wire in feet multiplied by the amperes of Current transmitted, and divided by the Volts lost in the line.*

Suppose, for instance, we wish to know how large a copper wire we must use to transmit 50 amperes over a wire 500 feet long with a drop of 10 volts in pressure. Putting 50 in place of $C$, 500 in place of $L$, and 10 in place of $V$, we have,

$$C.M. = \frac{10.5 \times 500 \times 50}{10} = 26,250.$$

Or, a wire having a cross section of 26,250 circular mils must be used. If a larger wire is used, there will be less than 10 volts lost in the line; and if a smaller wire is used, the loss will be greater. Referring to the table given in the next article, it will be found that a No. 6 wire drawn to the B. & S. gauge is of very nearly the size required.

Suppose now it is desired to supply current to an electric arc lamp which takes 5 amperes and requires a pressure of 100 volts for its operation. Suppose this lamp is 1000 feet from the electric generating apparatus, which means that the length of wire for the complete circuit will be 2000 feet. Also suppose that the generating apparatus will supply 105 volts pressure; then in order to have 100 volts at the lamp there must be only 5 volts lost in the line. Using the formula as before, we have,

$$C.M. = \frac{10.5 \times 2000 \times 5}{5} = 21,000,$$

or about a No. 7 B. & S. wire.

The circuit arrangement in the last example is quite analogous to the hydraulic illustration given in Article 102, Figure 46, where there is only a small loss of water pressure in the large connecting tank and most of the pressure is lost in the small pipes. In the case we are considering, most of the electric pressure is absorbed in the electric arc and the resistance of the lamp, only about 5 per cent of it being used in sending the current through the connecting wires.

If a group of, say, five similar lamps had been connected in parallel to the ends of the wire, there would have been 25 amperes to transmit. This is much as if there were five equal water-wheels taking water from one dam. All the wheels together would take five times as much current as one wheel, and each would utilize the full water pressure of the dam, as is described in the illustration in Article 259.

**330. Properties of Copper Wire.**—The following table gives useful data relating to the dimensions and properties of copper wire. The first column gives the numbers by which different sizes of wire are designated in the B. & S. gauge, which is the gauge most largely used in this country. The second column gives the diameters of the respective wires. The third column gives the circular mils[1] in each cross section; the fourth, the weights of bare copper wire per thousand feet. And the fifth and sixth columns give the resistances of a thousand feet of each size of copper wire at the temperatures of 60° and 75° Fahrenheit, respectively.

CHARACTERISTICS OF COPPER WIRE WHICH IS DRAWN TO THE BROWN AND SHARP (B. & S.) GAUGE

| B. & S. GAUGE | DIAMETER IN MILS | AREAS IN CIRCULAR MILS | WEIGHT PER 1000 FEET | RESISTANCE PER 1000 FT., IN OHMS | |
|---|---|---|---|---|---|
| | | | | 60° F. | 75° F. |
| 0000 | 460 | 211,600 | 641 | .048 11 | .049 66 |
| 000 | 410 | 168,100 | 509 | .060 56 | .062 51 |
| 00 | 365 | 133,225 | 403 | .076 42 | .078 87 |
| 0 | 325 | 105,625 | 320 | .096 39 | .099 48 |
| 1 | 289 | 83,521 | 253 | .121 9 | .125 8 |
| 2 | 258 | 66,564 | 202 | .152 9 | .157 9 |
| 3 | 229 | 52,441 | 159 | .194 1 | .200 4 |
| 4 | 204 | 41,616 | 126 | .244 6 | .252 5 |
| 5 | 182 | 33,124 | 100 | .307 4 | .317 2 |
| 6 | 162 | 26,244 | 79 | .387 9 | .400 4 |
| 7 | 144 | 20,736 | 63 | .491 | .506 7 |
| 8 | 128 | 16,384 | 50 | .621 4 | .641 3 |
| 9 | 114 | 12,996 | 39 | .783 4 | .808 5 |
| 10 | 102 | 10,404 | 32 | .978 5 | 1.01 |
| 11 | 91 | 8,281 | 25 | 1.229 | 1.269 |

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[1] Article 99.

CHARACTERISTICS OF COPPER WIRE WHICH IS DRAWN TO THE BROWN AND SHARP (B. & S.) GAUGE (*Continued*)

| B. & S. GAUGE | DIAMETER IN MILS | AREAS IN CIRCULAR MILS | WEIGHT PER 1000 FEET | RESISTANCE PER 1000 FT., IN OHMS | |
|---|---|---|---|---|---|
| | | | | 60° F. | 75° F. |
| 12 | 81 | 6,561 | 20 | 1.552 | 1.601 |
| 13 | 72 | 5,184 | 15.7 | 1.964 | 2.027 |
| 14 | 64 | 4,096 | 12.4 | 2.485 | 2.565 |
| 15 | 57 | 3,249 | 9.8 | 3.133 | 3.234 |
| 16 | 51 | 2,601 | 7.9 | 3.914 | 4.04 |
| 17 | 45 | 2,025 | 6.1 | 5.028 | 5.189 |
| 18 | 40 | 1,600 | 4.8 | 6.363 | 6.567 |
| 19 | 36 | 1,296 | 3.9 | 7.855 | 8.108 |
| 20 | 32 | 1,024 | 3.1 | 9.942 | 10.26 |
| 21 | 28.5 | 812.3 | 2.5 | 12.53 | 12.94 |
| 22 | 25.3 | 640.1 | 1.9 | 15.9 | 16.41 |
| 23 | 22.6 | 510.8 | 1.5 | 19.93 | 20.57 |
| 24 | 20.1 | 404 | 1.2 | 25.2 | 26.01 |
| 25 | 17.9 | 320.4 | .97 | 31.77 | 32.79 |
| 26 | 15.9 | 252.8 | .77 | 40.27 | 41.56 |
| 27 | 14.2 | 201.6 | .61 | 50.49 | 52.11 |
| 28 | 12.6 | 158.8 | .48 | 64.13 | 66.18 |
| 29 | 11.3 | 127.7 | .39 | 79.73 | 82.29 |
| 30 | 10.0 | 100 | .3 | 101.8 | 105.1 |
| 31 | 8.9 | 79.2 | .24 | 128.5 | 132.7 |
| 32 | 8 | 64 | .19 | 159.1 | 164.2 |
| 33 | 7.1 | 50.4 | .15 | 202 | 208.4 |
| 34 | 6.3 | 39.7 | .12 | 256.5 | 264.7 |
| 35 | 5.6 | 31.4 | .095 | 324.6 | 335.1 |
| 36 | 5 | 25 | .076 | 407.2 | 420.3 |

An inspection of this table shows that with every tabular difference of three "numbers" in the sizes of the wires there exists a ratio of nearly 2 to 1 in the areas of the wires. Thus the cross section of No. 18 has an area of 1600 circular mils, while No. 15 has an area of 3249 circular mils, and No. 21 has an area of 812.3 circular mils. Again, the cross section of No. 0 has an area of 105,625 circular mils, while No. 0000 has an area of 211,600 circular mils, and No. 3 has an area of 52,441 circular mils.

The Birmingham or Stubs wire gauge (B. W. G.) is sometimes used to designate copper wire, and quite commonly used to designate iron wire. The diameters of wires drawn to this gauge are given in the following table: —

| Number | Diameter in Mils | Number | Diameter in Mils | Number | Diameter in Mils | Number | Diameter in Mils |
|---|---|---|---|---|---|---|---|
| 0000 | 454 | 7 | 180 | 17 | 58 | 27 | 16 |
| 000 | 425 | 8 | 165 | 18 | 49 | 28 | 14 |
| 00 | 380 | 9 | 148 | 19 | 42 | 29 | 13 |
| 0 | 340 | 10 | 134 | 20 | 35 | 30 | 12 |
| 1 | 300 | 11 | 120 | 21 | 32 | 31 | 10 |
| 2 | 284 | 12 | 109 | 22 | 28 | 32 | 9 |
| 3 | 259 | 13 | 95 | 23 | 25 | 33 | 8 |
| 4 | 238 | 14 | 83 | 24 | 22 | 34 | 7 |
| 5 | 220 | 15 | 72 | 25 | 20 | 35 | 5 |
| 6 | 203 | 16 | 65 | 26 | 18 | 36 | 4 |

It will be noticed that the diameters given in this table through a limited range (*from No. 5 to No. 15*) do not greatly differ from the diameters of the wires in the B. & S. table through a similar range, *which begins at No. 3 and ends at No. 13.*

**331. The Electrical Distribution of Power.** — The volts "drop"[1] in a transmission wire is fixed by the pressure at the dynamo or battery, and the percentage of that pressure which may be reasonably sacrificed in the transmission. For instance, if the pressure at the dynamo is 125 volts, and it is considered reasonable to allow a loss of pressure equal to 10 per cent of this, then the "drop" of pressure is 12.5 volts.

It has not been found commercially possible to produce incandescent lamps for a higher pressure than about 115 volts until recently, and, consequently, nearly all incandescent lighting with continuous currents is done at a pressure between 100 volts and 115 volts, and each sixteen-candle-power lamp takes about one-half an ampere of current. If by some means the pressure at the lamps could be doubled without any change in the amount of light given out for each hundred watts, then each sixteen-candle-power lamp would require only about one-fourth of an ampere.

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[1] Article 329.

The pressure being doubled, the number of volts in a given percentage loss would also be doubled. We see, therefore, that the current divided by the "drop" is only one-fourth as great with the double pressure, so that *the wires required to carry current a fixed distance for 200-volt lamps need be only one-fourth as heavy as those required to carry current for the same number of 100-volt lamps.* Or, putting the statement in another way, the weight of copper which is required to supply current at a fixed percentage loss of pressure to a number of 100-volt lamps at a certain distance from the dynamo *will, at double the pressure, serve to supply four times as many lamps.*

In the same way, it may be seen that if the pressure is increased from 100 volts to 300 volts, the wires required to convey a given supply of power a certain distance may be reduced to one-ninth as great a cross section, and, therefore, to one-ninth the weight of those required for the 100-volt distribution.

The general rule may be given as follows: *When a given amount of power is transmitted by electricity over a certain distance at a fixed percentage loss, the cross section of the wires, and, therefore, their weight, is in inverse proportion to the square of the pressure.*

This rule applies equally, whether the current is used for producing light, operating stationary motors, running street cars, or for other purposes. The distribution of electricity by means of wires from a dynamo at one point to be used at other points is **Electrical Distribution of Power,** whatever may be the purposes for which the current is used, and the laws of transmission and distribution apply equally in one case as another. Electric lamps, arc or incandescent, may be operated on the same circuits with electric motors or electric heaters; or electric lamps may be taken out of a circuit and electric motors put in their place, or *vice versa,* without altering the conditions. It is well known that in many cities electric arc and incandescent lamps, stationary motors, and electrically heated flat-irons and curling irons are all furnished with the power necessary for their operation from the same circuits. Electric street cars are often furnished with light, heat, and power from the current conveyed to the car by the trolley wire.

## QUESTIONS

1. What wood is ordinarily used for electric poles? For cross arms? For pins?

2. Why are cross arms set in pairs facing each other?

3. How should a pole line be guyed or braced?

4. What is the smallest size of copper wire that should be used on a pole line?

5. What size of wire is used in arc circuits?

6. Do overhead telegraph and telephone wires ordinarily have an insulated covering?

7. Why are electric light circuits not grounded?

8. How is a pole line erected?

9. How are wire joints made?

10. What happens if the insulation of a telegraph line is poor?

11. Should electric light lines be well insulated?

12. What is weather-proof wire?

13. What kind of insulating supports are used for supporting overhead telephone and telegraph wires? For light and power wires?

14. Why are lead coverings put on underground cables?

15. What are electric conduits? Manholes?

16. How are light and power cables insulated?

17. Why is crinkled paper used in insulating the wires of telephone cables?

18. Compare telegraph, telephone, and power cables.

19. How are lead-covered cable joints made?

20. What are "built-in" underground systems?

21. Describe the Edison "built-in" system.

22. What are feeders? What are mains?

23. Why are the conductors of a constant pressure lighting system divided into feeders and mains?

24. What is the formula for calculating the sizes of wires? How is it obtained?

25. What is the cross section (in circular mils) of a No. 0000 wire drawn to the B. and S. gauge? Of a No. 12 wire?

26. What is meant by "volts drop"?

27. How is the "volts drop" in a wire determined?

28. How much larger a wire is required to supply current to a group of 100-volt lamps than to supply it, with the same loss of pressure, to a group of 200-volt lamps which absorbs the same amount of power?

29. For transmitting a given amount of power, how does the cross section of the wires depend upon the pressure?

30. For transmitting a given amount of power at a fixed pressure, how does the cross section of the wires depend on the distance of transmission?

31. How does the weight of conductors depend on the pressure when the "drop" is a fixed percentage of the pressure? How does the weight depend on the distance of transmission when the pressure is fixed?

**332. Series and Parallel Systems.** — The series system of electric lighting in which all the lamps are in series[1] is illustrated in Figure 288. Suppose that the dynamo in this figure generates 550 volts, and each of the 10 lamps calls for 50 volts; then the lamps will use a total of 500 volts, leaving 50 volts for the loss in the line, or about 9 per cent. The line must be designed accordingly.

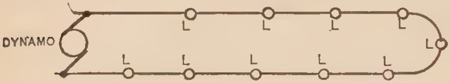

FIG. 288. — Diagrammatic Illustration of Series Arrangement of Lamps and Dynamo. *L, L, L,* Lamps.

Figure 289 indicates the parallel system of electric lighting in its simplest form. If in this case the lamps call for 100 volts and the dynamo generates 111 volts, there will be 10 per cent, or 11 volts, to be lost in the line. In calculating the size of wire the distance taken would be from the dynamo to *AA*, the most central point in the group of lamps. If the distribution is more complex, as in Figure 290, and a total drop of, say, 10 per cent is to be allowed from dynamo to lamps, the main line or *feeder* would be calculated from the dynamos to *AA* (the central point from which the branches or *mains* leave the feeders) with a drop of, say, 8 per cent. Then each branch would be calculated as in the simple case illustrated in Figure 289, using the remaining drop, which in this case is 2 per cent. The point *AA* in the figure is called the **Centre of Distribution** of the system of conductors.

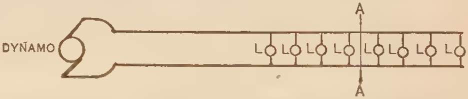

FIG. 289. — Diagrammatic Illustration of Parallel Arrangement of Lamps and Dynamo. *L, L, L,* Lamps.

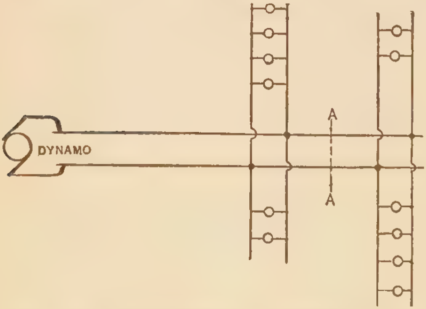

FIG. 290. — Diagrammatic Illustration of Parallel System with Lamps connected to Several Branch Lines.

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[1] Article 252.

**333. Multiple Series Systems.** — It is very easy to make the pressure quite high in circuits which are arranged to transmit power from a central station to electric motors alone, and thus keep the weight of the wires required within a reasonable limit, since the electric motors may have their windings designed for any reasonable pressure. Five hundred volts is the pressure quite commonly used for direct current circuits which are specially intended to supply current to stationary motors and street-car motors. Incandescent lamps may be used on such circuits, but it is necessary to use them in sets of five 100-volt lamps connected in series (Fig. 291). This is the arrangement which is used for lighting electric cars. For general purposes, such an arrangement is not at all satisfactory, because all the lights of each set must either burn or be extinguished. It is not possible to have only one or two lamps of a set burn at once. Systems of this class are called **Multiple Series Systems.**

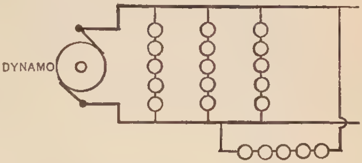

FIG. 291. — Diagrammatic Illustration of a Multiple Series Arrangement of Electric Lamps in which Sets of Five Lamps in Series are connected in Parallel with each other.

**334. Three-wire System.** — Two 100-volt lamps put in series on a 200-volt circuit are more satisfactory to use than five lamps in a set, but even such an arrangement is not suitable for general service. But the **Three-wire System** effects nearly as much saving in copper as is brought about by doubling the pressure through arranging the lamps in series of two, and yet the individual lamps of the three-wire system are entirely independent. A diagram of the arrangement of the three-wire system is shown in Figure 292. *A* and *B* are two dynamos; the positive terminal of the first is connected to the positive line wire, the negative terminal of the first is connected to the positive terminal of the second, and the negative terminal of the second is connected to the negative line wire. A third wire called the **Neutral Wire** is connected at a point between the two dynamos and runs out along the line with the positive and negative wires. Some of the electric lamps are connected in parallel between the positive and neutral wires, and the others are connected in parallel between the negative and neutral wires, the lamps being arranged so that the numbers on the two sides of the system are as nearly equal as possible, and so that the numbers of lamps likely to burn at one time are nearly equal for the two sides. When this condition is fulfilled as shown in the figure, the system is said to be **Balanced**, and the current flows from the positive pole of the first dynamo through the positive wire to the lamps on the positive side, through these lamps to the neutral wire, and thence directly through lamps on the negative side to the negative wire, and finally through the negative wire to the negative terminal of the second dynamo.

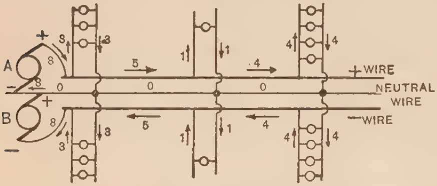

FIG. 292. — Diagrammatic Illustration of Balanced Three-wire System of Electrical Distribution.

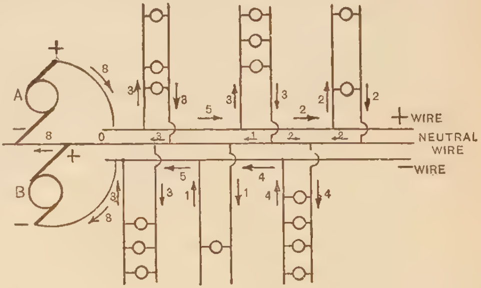

FIG. 293. — Diagrammatic Illustration of Balanced Three-wire System of Electrical Distribution.

If the system is balanced, no current returns to the dynamos through the neutral wire, and the dynamos operate exactly as though they were simply connected in series. The function of the neutral wire is then to distribute the current from the lamps on the positive side of the system to those on the negative side. But if the system is not balanced and more lamps are in use on one side of the system than on the other, the extra current is delivered by or returned to the dynamos through the neutral wire. Figure 293 shows by the arrows the way in which the current is distributed to the lamps on a balanced system in which the lamps

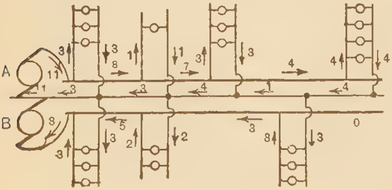

FIG. 294. — Diagrammatic Illustration of Unbalanced Three-wire System of Electrical Distribution. The numerals indicate the proportional currents flowing in different parts of the circuit.

are not exactly opposite each other. Figure 294 is a diagram of a three-wire system with more lights connected to the positive than to the negative side of the system. The arrows show the directions in which the current flows in the wires. The positive wire carries enough current to supply the lamps on the positive side of the system, and the difference between the current required to supply the lamps on the two sides returns through the neutral wire. The positive dynamo, therefore, carries more load than the negative dynamo. If each lamp is assumed to require one ampere in its operation, then the numerals in the figure represent the relative amounts of current which flow in the various paths of the circuit.

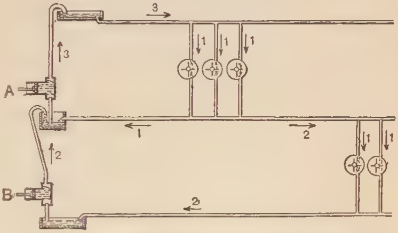

FIG. 295. — Diagrammatic Illustration of an Hydraulic Analogy to the Three-wire System of Electrical Distribution.

In Figure 295 the dynamos of the preceding figures are supposed to be replaced by pumps in an analogous arrangement, and the lamps are supposed to be replaced by water motors. The arrows show the directions of the streams of water in the system of piping when the pipes and motors are working.

The three-wire system is used to a very large extent by the electric lighting companies all over the world.

**335. Five-wire System.** — Plans for increasing the dynamo pressure used to supply incandescent lamps, such as the three-wire system which consists essentially in connecting the lamps practically in series and yet making them really independent of each other by means of a neutral wire, may be extended. Figure 296 is a diagram of an arrangement with four lamps in series and five wires. *A*, *B*, *C*, and *D* represent the dynamos. This arrangement, known as the *five-wire system*, has not come into much use in the United States.

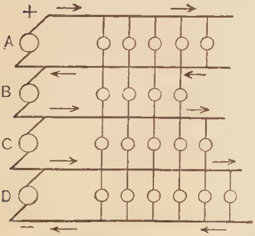

FIG. 296. — Diagrammatic Illustration of a Five-wire System of Electrical Distribution.

**336. Weights of Wire in Several Systems.** The weight of wire in a three-wire system of a certain pressure at the individual lamps amounts to a little more than one-fourth of the weight required for a two-wire system with the same pressure at the lamps. Since the pressure from positive to negative wire in the three-wire system is twice that of the two-wire system, one might suppose that only one-quarter as great a weight of wire would be necessary in the three-wire system for the distribution of current for a given number of lamps; but this is not true, because of the introduction of the neutral wire which adds to the total weight of wire required by the three-wire system. The actual weight required in the three-wire system is about three-eighths of that in a two-wire system. This saving in the weight of copper is a very important factor to large electric lighting companies, as their copper feeders and mains cost a great deal of money.

The saving effected by the five-wire system is proportionally greater than that brought about by the three-wire system, but it causes greater difficulty in keeping the pressure perfectly constant at the lamps.

**337. The Alternating Current System.** — The systems of distribution heretofore described are suitable for both direct and alternating currents. The possibility of transforming the pressure of alternating currents, however, permits the use of a high pressure on the transmission lines without increasing the pressure on the lamp circuits. Figure 297 represents such a system where the feeders carry from 1000 to 2000 volts pressure and the supply circuits are connected through transformers *A*, *B*, *C*, which reduce the pressure to an amount which is suitable for lamps or motors, and which renders the conductors safe to handle. The transformer *B* has its secondary connected so that it can be used on a three-wire system. Distributing systems for polyphase currents are similar in essential features of construction to the single-phase construction, except that three or four wires must be used and two or three transformers must be erected at each point of transformation.[1]

**338. High-pressure Long-distance Transmissions.** — The last articles refer especially to the distribution of electrical energy over limited areas such as the regions of electrical supply in individual towns. Within recent years it has been found possible to very greatly increase the distance of transmission by increasing the pressure, so that now many plants are operating which transmit power over distances up to eighty or more miles at pressures ranging from 10,000 to 60,000 volts. Recently, plants have been planned to transmit power at even higher pressures. There is every reason to suppose that both the pressure and distance will be still further increased during the next decade.

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[1] This is described more fully in Article 246.

Much trouble has been experienced in properly insulating the lines which are subjected to such high voltages. If the insulators become faulty, leakage of the current is apt to result, which chars and injures the wooden pins, cross arms, and poles, as well as causes trouble at the generating station, due to short circuits. A large triple petticoat insulator of porcelain which is used on many transmission lines, including the one which reaches from Niagara Falls to Buffalo, is illustrated in Figure 298. Insulators of this character are sometimes made as large as ten inches across. The conductor is laid in the groove at the top of the insulator and tied in position by a tie wire twisted around the neck of the insulator.

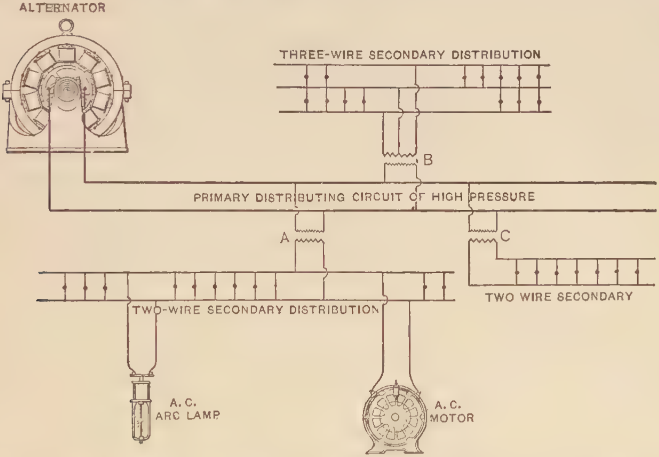
ALTERNATOR
THREE-WIRE SECONDARY DISTRIBUTION
B
PRIMARY DISTRIBUTING CIRCUIT OF HIGH PRESSURE
A
C
TWO WIRE SECONDARY
TWO-WIRE SECONDARY DISTRIBUTION
A. C. ARC LAMP
A. C. MOTOR

FIG. 297. — Diagrammatic Illustration of Alternating Current Circuits in which a High Pressure is distributed from the Generator and transformed into a Safe Pressure at Centrés of Use. The dots represent incandescent lamps.

Another difficulty that is encountered in the very high-pressure transmission is the prevention of loss due to static discharges which extend from conductor to conductor through the air. The loss from this cause, which may be considerable unless the wires are several feet apart, has not as yet been overcome. Insulating the wires with a continuous covering is of comparatively little service, and, in fact, the conductors of such lines are usually bare.

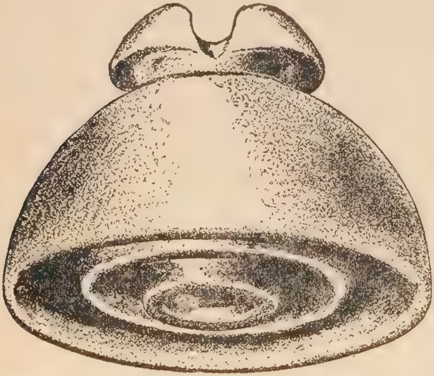

FIG. 298.— Porcelain Insulator for Use with High-pressure Circuits for the Electrical Transmission of Power over Long Distances.

The currents for long-distance transmission of power by electricity are usually generated at ordinary pressures, and the high transmission pressures are obtained by means of "step-up" transformers at the power house, which increase the pressure of the generator to that required for the line. This is again reduced in sub-stations or transformer houses at points where the energy is to be used. The distribution from the sub-station to the users is similar to that described in the last article. Three-phase systems are ordinarily used for work of this class, though the three-phase current is often transformed into two-phase at the receiving end by proper transformer combinations.

With increasing knowledge gained by experience and scientific discovery it will become possible to increase the pressure to higher and higher values, and thus it will become more and more economical to transmit power from natural water-power sources, coal mines, and gas countries by electrical means to very widely situated centres. This development points out a road which apparently leads to wonderful applications of electrical power.

**339. Fire Underwriters' Rules.** — The importance of using the utmost care in laying out and putting in place the electric light wires which go into houses is reasonably well recognized. It now comes to an explanation of the more important rules for this work which have been issued by various associations of fire insurance companies or underwriters. These associations issue rules for carrying on electrical wiring, and in the large cities supervise or inspect the work in order that danger from fire may not be introduced into buildings insured by them. Many of the chances for accident which exist in electric plants are caused through carelessness or lack of knowledge on the part of inexperienced wiremen who may be employed on account of the false economy of the owner of the plant. In electrical work, the cheapest is by no means always the best; but it is often difficult to make this fact apparent to the owner of a building who must pay for expensive wiring, and a carefully enforced set of rules for the wiring is the best safeguard which the owners of buildings and the underwriters have against dangers caused by careless workmen and poor workmanship.

The following points require to be specially looked after: —

1. That the general workmanship is good, and especially that joints in conductors (which should be as few as possible) are well made and well insulated.

2. That the conductors have ample cross section.

3. That the insulating material on the conductors is of the very best, and that the insulation resistance of the completed wiring is high.

4. That *absolutely no portion of the electric circuit touches any part of the building*, but is separated at every point by porcelain cleats, knobs, or tubes, or by conduit and moulding.

5. That the insulation resistance of the wiring is tested from year to year to ascertain whether or not it is deteriorating.

6. That all constant pressure circuits are properly protected by safety fuses.

By insulation resistance is meant the resistance as measured from either of the conductors of the plant to the ground, or from one conductor to the other. Practical methods for making insulation tests will be explained in the next chapter. The actual resistance of the insulation on the wiring in any particular building always depends upon the length of wire, number of lamps, and character of the fixtures used in the installation. Thus, for instance, if wire is used which has an insulation resistance of 1500 megohms per mile, and ten miles are used, the total insulation resistance of the wire cannot be expected to be more than 150 megohms; while if only two or three miles of wire are used, the total insulation resistance may be expected to be greater. As a general rule, leakage at joints, lamp sockets, fuse blocks, and fixtures of all kinds, has a much more marked effect on the insulation resistance of new wiring than does the leakage through the covering of the wire itself, so that the underwriters require these points to be specially well looked after. It is usual to expect a much higher insulation in wiring before the sockets and fixtures are connected up than afterward, and in some places the insulation resistance which is required in any plant is allowed to depend upon the number of lamps which are connected to the wires.

Unless the best of materials and workmanship are used for the wiring put in a building, the insulation resistance will begin to fall within a few months, even though it was very high when the wiring was first put in. This fall in the quality of the insulation is due to several causes, chief among which are poorly insulated joints and inferior rubber in the covering of the wires. Portions of wiring which have been in service from a few months to a few years have been found to be so deteriorated that in certain spots the rubber coverings on the wires have practically all rotted away. It is sufficient to say that good rubber-covered wire does not fail in this manner. On account of the deterioration of poor material, an inspection is made of wiring from time to time in some cities; and if any short branch or "tap" falls below 100,000 ohms in insulation, measured between the wires and the ground or between the wires themselves, it must be repaired.

**340. Use of Safety Fuses.** — It is necessary to use safety fuses on all constant pressure circuits. Safety fuses must be of such a capacity that they will *blow*, or melt, *just above the rated carrying capacity of the smallest wire which they protect.* It is customary to place fuses at every point where a change is made in the size of wire, even where small fixtures or drop cords are attached to the tap lines, and not more than a dozen sixteen-candle-power incandescent lamps are permitted on one "tap," except under special conditions.

Automatic **Circuit Breakers** are often used in place of fuses at important points, and they are commonly used for the protection of the generators against excessive loads in railway power stations and some electric light stations. They consist of switches which are caused to automatically open the circuit by means of a spring and trigger actuated by an electromagnet when the current exceeds a proper value.

**341. Safe Carrying Capacity of Wires.** — In general, the size of a fuse depends upon the size of the smallest conductor it protects, and not upon the amount of current to be used in the circuit. Below is a table showing the safe carrying capacity of copper conductors of different sizes in B. & S. gauge, as given in the generally accepted rules issued by the National Board of Fire Underwriters: —

| Size of Wire B. & S. Gauge | Currents in Amperes which it is Safe for Interior Wires to carry continuously | |
|---|---|---|
| | Rubber covered (Open work or concealed) | Weather-proof insulation (Open work) |
| 0000 | 210 | 312 |
| 000 | 177 | 262 |
| 00 | 150 | 220 |
| 0 | 127 | 185 |
| 1 | 107 | 156 |
| 2 | 90 | 131 |
| 3 | 76 | 110 |
| 4 | 65 | 92 |
| 5 | 54 | 77 |
| 6 | 46 | 65 |
| 8 | 33 | 46 |
| 10 | 24 | 32 |
| 12 | 17 | 23 |
| 14 | 12 | 16 |
| 16 | 6 | 8 |
| 18 | 3 | 5 |

The safe carrying capacities of insulated aluminum wires are 84 per cent of the capacities for copper wires which are given in this table.

By "open work" in this table is meant construction which admits of all parts of the surface of the insulating covering of the wire being surrounded by *free* air. The carrying capacities of Nos. 16 and 18 wire are given, but no wire smaller than No. 14 is to be used, except for the wiring of metal fixtures which support incandescent lamps under proper conditions.

**342. National Code of Rules.** — Until within the last few years, no uniformity existed in the rules which were in force in different parts of the country, but the associations of the underwriters located in various cities or districts made their own rules. This resulted in much annoyance, and did not tend to produce the best workmanship; and it was found to be of advantage to formulate a satisfactory set of rules for general adoption, which was done by a committee of the underwriters working in harmony with various societies of electrical engineers and electric light experts.

The set of rules thus approved is called the National Electrical Code. Printed copies of the Code can be obtained from the local inspectors, or from the secretary of the National Board of Underwriters in Chicago.

The approved rules divide electric light and power circuits into six classes: —

1. The circuits inside of central stations and the dynamo rooms of isolated plants.

2. Constant current circuits, usually constructed for the purpose of operating arc lamps or other devices in series.

3. High-pressure circuits, which are usually alternating current lines.

4. Low-pressure circuits, which include all low-pressure inside wiring and some outside lines. (Low-pressure circuits are taken to include all circuits, except grounded electric railway circuits, on which the pressure does not exceed 550 volts.)

5. Grounded electric railway circuits.

6. Extra high pressure circuits. (These include all circuits of over 3500 volts pressure.)

For each of these classes of circuits, special rules are directed toward the perfect safety of the systems which especially emphasize the very essential points referred to above. Every rule has a good reason for its existence, and experience has shown its propriety. Circuits of the fifth and sixth classes are refused admission to any buildings for the purpose of furnishing electric light and power except in the power houses, substations, and car barns of the electric companies.

The only classes of wiring with which the underwriters' rules do not deal directly are connected with telephone, district messenger call, burglar alarm, electric bell, and similar systems which are operated by electric batteries. Even in regard to these wires the rules enjoin proper precautions to prevent electric light and power wires from becoming crossed with the poorly insulated battery circuit wires.

**343. Wiring Buildings.** — The importance of the parts of electric lighting circuits which are inside of buildings cannot be overestimated. A central station may be built upon the best plan to supply current through a perfect distributing system, but a safe and satisfactory light will not be given if the **Inside Wiring** is poorly planned and badly put in place. Fires which occur on account of the electric light wires in houses are always caused either by the use of poor material, careless planning, or bad workmanship when the inside wiring was put in, and *if the wiring is done properly, it is almost impossible for fires to be caused by an electric lighting or power system.* On the other hand, *poorly constructed wiring should not be permitted anywhere.*

On account of the danger which may be caused by unscrupulous or untrustworthy wiremen, it is usual in large cities to have official inspectors who examine and test all electric light work placed within buildings. It is the duty of these inspectors to see that the work is safely and properly done in accordance with rules fixed by the city authorities and approved by the fire underwriters. Even with such inspection the work is not always done in the best manner; yet comparatively few important fires have been caused by electric wires, and those have usually been the result of dense ignorance or worse, — carelessness. A great majority of the accidents laid to the door of electricity are due to some other cause.

*For ordinary wiring inside of a building only the very best rubber-covered wire should be used.* A great many factories produce rubber-covered wire for use in inside wiring, and much of it is very poor, so that considerable care is necessary in selecting material.

**344. Cleat and Moulding Work.** — The wires may be run in buildings according to three entirely different methods. In the first place, the wires may be run upon the surfaces of ceilings or walls in plain sight, where they are held in place by means of cleats made of porcelain, or, if more convenient, porcelain knobs may be used. This is a common arrangement of wiring in small stores and other buildings where the position of the wires in plain sight is not objectionable. As the wires are all visible and therefore can be easily inspected at any time, **Open Work**

or **Cleat Work**, as this arrangement is called, is a safe and satisfactory arrangement of wiring, provided the wires and appliances are all out of reach so that they cannot be tampered with.

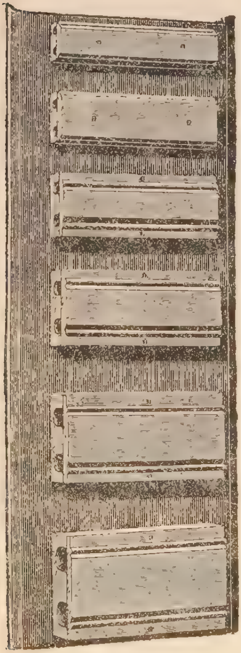

FIG. 299. — Samples of Wood Mouldings for Electric Light Wires. These samples are shown nailed to a board for exhibition.

There are many places where the appearance of open work is objectionable, but where the wires may be placed in wooden casings or **Mouldings** which are fastened to ceilings or walls in plain sight. This is an exceedingly safe and satisfactory arrangement, since the wires are well protected from mechanical injury or from being tampered with, and yet the condition of the wiring may be easily seen at any time by a simple inspection. Common forms of mouldings are shown in Figure 299. These may be made of any desired wood, though hard pine is most commonly used.

**345. Concealed Work.** — In the third method of running wires they are placed entirely out of sight, or **Concealed**. This may be done in various ways. The oldest and at the same time the least safe and satisfactory way was to fasten the wires to the ceilings and walls of the building before the plastering was put on. The wires were then entirely covered by or embedded in the plaster, so that it was impossible to examine or repair them without injury to the walls; and, indeed, the positions of the wires in the walls were often forgotten in a few months after the building was finished, so that repairs were doubly difficult to make. This arrangement of the wires was made more unsafe because the plaster upon the walls often spoiled the insulating qualities of the rubber coverings, and the wires became "grounded" as a consequence. The arrangement is no longer permitted by the underwriters.

In buildings with wooden floors and partitions it is permissible to fasten the wires to the floor joists or partition studding by means of porcelain cleats or knobs in such a way that the wires do not touch anything except their insulating supports, while porcelain or other tubes surround the wires wherever they pass through walls or joists. When this is properly done, the wires are not likely to be injured by plaster or dampness, but the disadvantage that they cannot be examined is still present. They are also liable to injury by plumbers, carpenters, or other workmen who are engaged in making repairs or alterations to the building.

It is much better to arrange a hidden conduit to contain the concealed wires. This may be placed behind decorations or other objects on the walls or may be laid neatly under the floors or the plaster. Special tubes are made to be used as "conduits" for inside wiring. These are called "interior conduit," "loricated pipe," and other trade names, and they are used to a large extent. They are essentially nothing more than strong, smooth, water-tight iron tubes, composed of iron pipes with varnished or enamelled interiors. Interior tubing made of insulating material was originally intended to take the place of the rubber insulation on the wires so that they could be used with a cheap cotton covering, but it was found to be necessary to use the best rubber insulation on wires in the tubes in order that the wiring might give satisfaction, and the insulating tubes are not often used now. The advantages of tubes lie in the fact that the wires are protected from mechanical injury and from contact with plaster, moisture, and other deleterious agencies. These tubes should be so constructed that the wires may be readily pulled into or out of them at any time, so that alterations or repairs may be made whenever required.

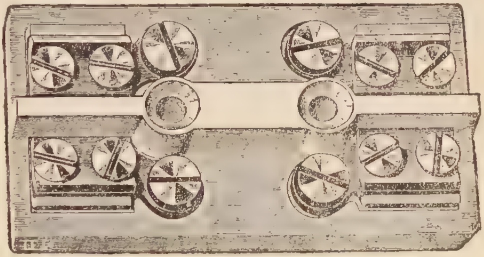

FIG. 300. — Main Fuse Block.

**346. Distributing Systems for Wiring Buildings.** — The plan of the wiring in a building depends a great deal upon the size and construction of the building, but in its details it should always fulfil, not only in the letter but in the spirit, the requirements of the underwriters which are laid down in the special printed rules called the National Electrical Code. In small buildings supplied with current from a central station the simplest plan for concealed wiring is what may be called the "central cabinet plan." Heavy service wires are led from the street mains of the electric light company through a fuse block or cut-out (Fig. 300) to a convenient central point in the building. At this point the main wires terminate in a cabinet which contains a number of fuse blocks from each

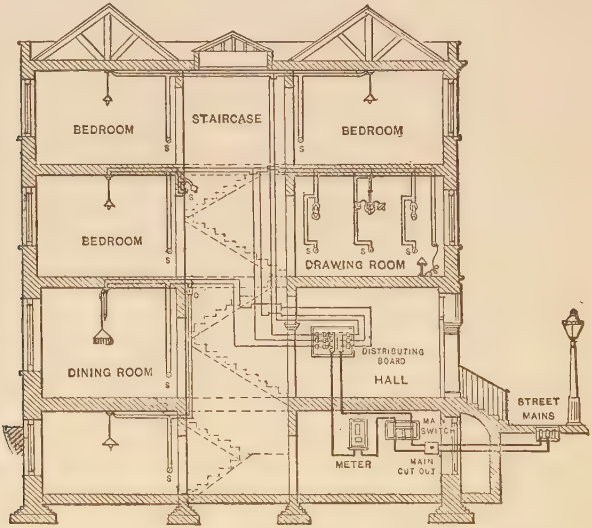

FIG. 301. — Diagrammatic Scheme of Wiring for a Residence.

of which a circuit of smaller wires runs out to supply a limited number of lamps, which is usually between 5 and 15. Figure 301 shows such a plan of wiring so plainly that an extended description is not necessary. In the figure, *S*, *S*, *S* are switches for turning the lights on and off, and *C* is a fuse block used to protect a small branch circuit which for convenience is connected to one of the **Taps** instead of being run back to the distributing centre. By this arrangement of the distribution any serious trouble which occurs on one branch or tap causes the fuses at the distributing centre which belong to the branch to melt. This disconnects the defective branch from the service wires without interfering with the other branches. The location of all the fuse blocks at a central point makes it convenient to replace fuses, and the fuse blocks can be so protected that a fire cannot possibly be caused by the arc which sometimes occurs when a fuse melts or **Blows.**

Another plan for wiring a building is shown in Figure 302. In this figure a heavy trunk circuit runs from the main cut-out in the cellar to the top of the house, and the lamp taps branch off from the trunk at each floor. *S, S, S* are switches for controlling the lights, and *C, C, C* are fuse blocks. This plan makes it necessary to scatter the fuse blocks through different parts of the house, which is a disadvantage.

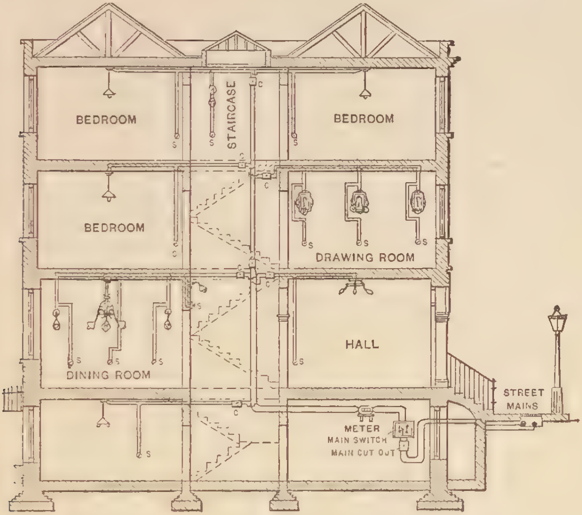

FIG. 302. — Diagrammatic Scheme of Wiring for a Residence.

In large buildings a combination of the two plans just explained is used, and feeding trunks, or feeders, are run from the main fuse block to several distributing centres at convenient points in the building. One feeder with its mains is illustrated in Figure 303, where *AB* is the feeder running from the main cut-out, or from the dynamo room if a special lighting plant is located in the building, and *C, C, C, C* is a main which runs down and up so as to supply current to the different floors of the building. Fuse blocks are placed at each rectangle to protect the parts of the circuit beyond it. The horizontal lines are mains which run along each floor to carry current to the distributing centres, which are shown by the rectangles at *X*, *X*, *X*. The lamp taps, which are run from the centres to the lamps, are represented by the short lines which run out from the rectangles. A dozen or more taps often radiate from a single centre. Only one line is used in this figure to represent the circuit, which may be either two-wire or three-wire.

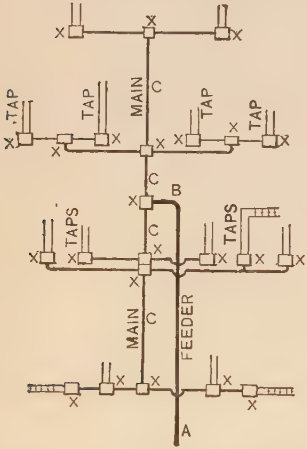

FIG. 303. — A Feeder and Main System for Large Buildings. A single line is used to represent both conductors of the circuit.

For very large buildings the plan shown in Figure 303 may be extended by running feeders to various points in the building, from which points mains run to the distributing centres. The feeding points are then usually joined together by a heavy connecting circuit, often called a **Crib**. In Figure 304, *A*, *A*, *A*, *A* are feeders running to four feeding points in a building, which are marked *B*, *B*, *B*, *B*. These points are joined together by the crib from which the mains *C*, *C*, *C*, *C* run off to the various centres of distribution.

**347. Sizes of Wire for Inside Wiring.** — The wiring plan in a large building is seen to be quite similar to the plan of the feeders and mains used in distributing electric current from a central station.[1] The object to be aimed at in arranging the wires in either case is to keep all of the lamps which are burning at one time at as nearly as possible the same pressure, and also to make it possible to keep the pressure constant, regardless of the number of lamps burning. The size of wires used at any place must be calculated from the amount of current which the wires carry, and the volts drop (or loss in pressure) which is allowed. The calculation sometimes indicates a wire which is too small for safety, as a wire smaller than No. 14 B. & S. gauge should never be used for inside electric light wiring; neither should the current passed through a wire exceed the "safe carrying capacity" given in the table which is printed in Article 341. "Wiring tables," which give the sizes of inside wires which are required to supply current to lamps at various distances from the main cut-outs, are to be found in many trade catalogues and various small special books.

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[1] Article 328.

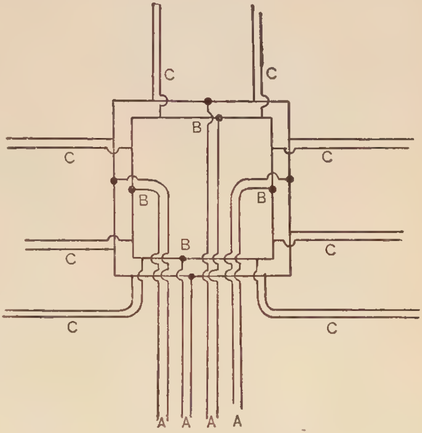

FIG. 304. — Arrangement of Feeders and Mains for Large Buildings.

**348. Fuses.** — A great many details relating to inside wiring can only be learned by observing wiring which has been completed in a proper manner, but a great deal of useful information relating to the incidental material can be obtained from the catalogues of the companies who supply electrical material. The most important incidental material consists of fuse blocks, fuses, switches, and sockets.

Fuse blocks now invariably consist of porcelain bases of various forms upon which are carried terminal screws for the connection of the fuses and the circuit wires. Electric light fuses are strips or wires of a metal alloy which melts at a temperature that is so low that the melted metal cannot possibly cause harm. The alloy is usually made largely of lead and tin, but varies a great deal.

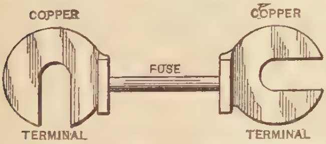

FIG. 305. — Fuse of "Link" Pattern, with Copper Terminals.

The object of the fuse is to protect the wires beyond it from becoming overheated through some accident. The size of the fuse at any point is such that if anything occurs to cause an unsafe current to flow through the wires protected by it, the fuse will melt and cut the wires out of the circuit. Fuses of large carrying capacity are composed of strips or "links" of fuse metal which are tipped at each end by a terminal of copper (Fig. 305), so that a more substantial contact may be made with the fuse block terminals. Fuses of small capacity are also made of the "link" pattern, but plug fuses, such as are illustrated in Fig. 306, are very commonly used where currents do not exceed thirty amperes.

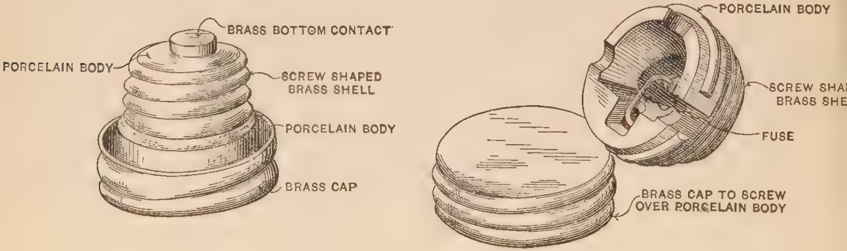

FIG. 306. — Edison Plug Fuse.

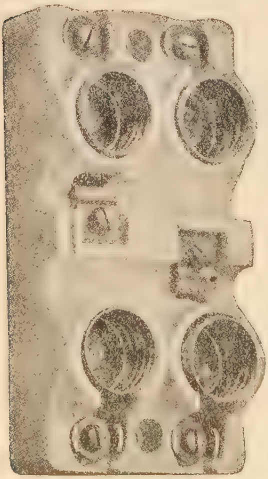

FIG. 306*a*. — Edison Plug Fuse Block.

**348 *a*. Switches.** — Each of the house switches, or "snap" switches, that are now generally used to control electric light "tap" circuits, consists of a small electric circuit closer arranged with a spring so that it opens or closes the circuit with a snap when the handle is moved. The quick action prevents the switch points from becoming burned by the spark upon opening the circuit. A switch is called **Double Pole** when it carries separate blades which simultaneously control the two wires of a circuit. A **Single Pole** switch controls only one wire of a circuit.

The blades of central station switches usually make a rubbing contact between substantial leaves of copper when the circuit is closed through them.

## QUESTIONS

32. What is a series system? A parallel system?

33. How should the drop in pressure be divided between feeders and mains in a parallel system?

34. What is a multiple series system?

35. What are the advantages and disadvantages of the multiple series system for incandescent lighting?

36. What is the three-wire system?

37. What is the function of the neutral wire in a three-wire system?

38. Why does no current flow to or from the dynamos over the neutral wire of a balanced three-wire system?

39. Give a hydraulic analogy to the three-wire system.

40. How much copper is saved by the three-wire system?

41. What is a five-wire system? How much copper is saved by it?

42. Describe an alternating current system.

43. What are the advantages of alternating currents for electric transmission of power?

44. Over what extremes of distance has electric power been transmitted by means of alternating currents? At what pressures?

45. What kind of insulators are used for very high pressure lines?

46. What is a "step-up" transformer?

47. Describe a high-pressure transmission system.

48. Why are underwriters' rules necessary?

49. What points must be especially looked after in the electric wiring of houses?

50. Why are poorly constructed sockets, fuse blocks, and fixtures particularly likely to be the seats of bad insulation?

51. What rules are now generally used to govern wiring?

52. Why must safety fuses be made to protect the smallest wire in a circuit? Will larger wire in the same circuit then be protected?

53. Is it permissible for any part of the wiring of a building to rest against the building materials?

54. What should be the minimum insulation resistance of individual taps?

55. How much current will a No. 0000 wire safely carry? How much a No. 12?

56. What kind of wire should be used for inside work?

57. How is cleat and moulding work executed?

58. How is concealed work executed?

59. What is interior conduit? How is it used?

60. How is the feeder and main arrangement used for interior wiring?

61. What is the crib system of interior wiring?

62. Where and how is it desirable to arrange the fuses in a building?

63. Describe a fuse and a fuse block.

# CHAPTER XXI

## APPLICATIONS OF ELECTRICAL INSTRUMENTS TO THE TESTING OF LINES AND CIRCUITS

## MEASUREMENTS OF ILLUMINATION

**349. Troubles in Telegraph and Telephone Lines.** — On account of their exposed positions, overhead telegraph and telephone wires are particularly liable to injury. It is therefore necessary to make careful, systematic, and continued tests of important lines in order that they may be kept in satisfactory condition. The troubles to which lines are heir may be divided into four classes : —

1. Grounds.
2. Crosses.
3. Poor connections.
4. Breaks.

A line is said to be **Grounded** when so much current leaks from it to the ground as to interfere with its proper use. Grounding may be caused by a general leakage all along the line, or a large leak may exist at one point, where the line comes in contact with trees, etc. When the insulation of the line becomes so low that practically all the current leaks off, it is said to be **Dead Grounded.**

Lines are said to be **Crossed** when they make contact with each other so that current sent over one line may stray on to the other. When telegraph or telephone lines are crossed, only one of them can be used to send independent messages, since the messages sent over one line may be received on the others, and if it is attempted to use the several lines at the same time, the various messages become badly mixed up.

The most fruitful cause of crosses is the swinging of loose wires in the wind, by which means they become tangled up. Sometimes crosses or grounds will appear and disappear at intervals, when they are often called **Swinging Crosses** or **Grounds.** These may be caused by a swinging wire which touches another wire or a ground contact at intervals, but does not remain continuously in contact.

**Poor Connections** result from various causes, such as corroded joints in the wire, a corroded connection to a ground plate or water-pipe, a poor contact between the ground plate and the earth, loose connections at binding posts of instruments, at switchboards, or at batteries. Poor connections may very seriously reduce the conductivity of the line, and thus reduce the distinctness of messages sent over it unless extra battery power is used.

A **Break** may be caused by a binding post connection working entirely loose, by a wire breaking at an instrument, or by the line wire breaking. It may also be caused by defective contacts in the working parts of an instrument, or, in the case of a telegraph line, by a careless operator leaving his key open. When a line wire breaks, the circuit may be entirely opened, or if one or both of the ends get on the ground, it may be possible to get current through one or both portions.

**350. Simple Tests of Telegraph Lines.** — The simplest way of determining the condition of a line is by comparing the distinctness of the signals which are transmitted over it from day to day. Thus, in the case of a telegraph line, if signals going out from a terminal station where half the battery is located are found to be strong and good on a certain day, while signals coming into the same station over the same wire are weak and indistinct, it is evident that the insulation of the line is poor.[1] If the signals which are sent and received are equally indistinct, while the battery is in good condition, the conductivity of the line is probably less than usual. If signals sent over one wire can be received on another, the lines are either crossed or sufficient current leaks from one wire to the other to give the effect of a cross. In the case of a break which opens the circuit, the armatures of the relays in the line fall back from their magnets; but if the ends of the line at the break become grounded, it may be possible to send signals between stations upon the same side of the break.

The section between two stations upon which **Trouble** exists, may be readily located in the case of a local telegraph line passing through stations which are close together. To do this, the station nearest one end is called up from the end station, either by means of the faulty wire or by means of another wire, and is told to ground the faulty wire. This being done, signals are transmitted between the two stations over the faulty wire. If the wire works all right, the next station is called up and the test of the working condition of the wire is again made. This is continued from station to station until the signals fail in transmission. The trouble is then on the last section tested, and a lineman may be sent out to locate it exactly and correct it.

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[1] Compare Article 325.

**351. Tests of Telephone Lines.** — Trouble on telephone lines is usually shown to the exchange operator through difficulty or impossibility in communicating with a subscriber. Crosses may make themselves evident through the fact that when a subscriber on one of the crossed wires calls the exchange by working his magneto, not only does the drop fall which is attached to his wire, but the drops which are attached to the wires which are crossed with his also fall. What is known as **Cross Talk** between telephone wires is not a certain sign of a cross, as it may be caused by either electromagnetic or electrostatic induction.[1] The latter is a very common cause of cross talk. To avoid cross talk in telephone cables, the two wires of each metallic circuit are twisted together, and such a cable is therefore said to be made up of **Twisted Pairs.**

**352. Tests with Instruments.** — In the case of long **Trunk** telegraph or telephone lines connecting cities at a considerable distance apart, methods are required for the location of faults by direct electrical measurements. It is usual to make careful daily or weekly measurements of the insulation and conductivity and sometimes of the capacity of such lines. The results of these measurements are carefully recorded in a book, and the records are a material aid in the location of faults by electrical measurement. The usual instruments to be used in testing lines are a sensitive galvanometer[2] and a Wheatstone bridge.[3]

**353. Line Conductivity.** — To measure the conductivity of a metallic circuit is very simple. At one end of the line the two wires are connected together, and at the other end of the line the two wires are connected to the bridge (Fig. 307). Half the resistance measured by the bridge is the resistance of one of the wires composing the circuit, if the wires are of equal length and size.

[1] Articles 137 and 190.

[2] Article 146.

[3] Article 162.

When only one wire is available, as may be the case with telegraph circuits, its far end is connected to ground, the near end is connected to one of the binding posts of the bridge, and the other binding post, to which the unknown arm should be connected, is connected to ground, as shown at *E* in Figure 308, which shows the arrangements of the connections for a post-office pattern bridge.[1] With this arrangement, the arm of the bridge marked *A* in the diagrams, such as Figures 307 and 309,[2] is between *A* and *B*. The arm *B* is between *B* and *C*; the arm *R* is between *A* and *D* in the zigzag part of the bridge rheostat; and the unknown resistance is connected to the bridge at the points *C* and *D*. The resistance measured by the bridge may be taken as equal to the resistance of the line, provided the ground connections are good.

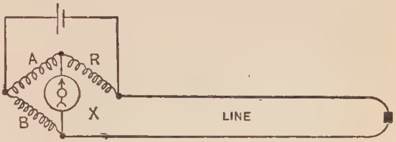

FIG. 307.—Diagram showing the Connection of Two Telegraph Lines, or a Metallic Circuit Telephone Line, with Wheatstone Bridge for the Purpose of measuring their Joint Resistance.

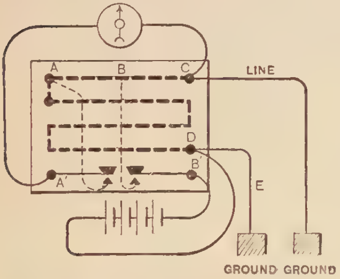

FIG. 308.— Diagram showing the Connection of One Grounded Telegraph or Telephone Line with Bridge for the Purpose of measuring its Resistance.

**354. Line Conductivity — Three Wires Available.** — When the individual conductivity of three wires running between the same points is desired, the measurement is very simple. The resistances of the wires taken in pairs (Fig. 309) is measured exactly as in the case of a metallic circuit. From these measurements the resistance of each wire may be calculated. For instance, if wires 1 and 2 taken together measure 4500 ohms, 1 and 3 taken together measure 3750 ohms, and 2 and 3 taken together measure 4700 ohms, then the resistance of all three wires in series would be

$$\frac{4500 + 3750 + 4700}{2} = 6475.$$

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[1] Article 164.

[2] Also see Article 163.

Wire No. 1 then measures the difference between the resistance of all in series, and that of Nos. 2 and 3 together, or the difference between 6475 and 4700. No. 1, therefore, measures 1775 ohms. In the same way wires Nos. 2 and 3 are found to respectively measure 2725 and 1975 ohms.

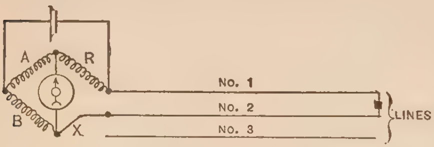

FIG. 309. — Diagram indicating Connections with Bridge where Three Wires are Available and it is desired to obtain the Conductivity of Each.

*Example A.* If it is found by bridge measurement that the resistance of three telegraph wires taken together in pairs are 3000, 4000, and 5000 ohms, what is the resistance of each wire? *Ans.* 3000, 2000, and 1000 ohms.

**355. Earth Currents.** — When resistance measurements are made with the earth as part of the circuit, currents flowing in the earth may interfere with the results by entering the wire and flowing along it. Such currents are called **Earth Currents.** At exceptional times, as, for instance, during the continuance of the so-called **Magnetic Storms,** *earth currents flowing on the wires may be so strong that telegraphing may be carried on without any battery attached to the wires.*

When earth currents interfere with the measurements made on a grounded circuit, the tests must be postponed until a more favorable opportunity, if additional wires cannot be used in making the measurements by the last method given above.

**356. Line Insulation.** — Exact insulation measurements are made with the line disconnected from its ground plates (the line **Open,** Figure 310). As a general rule, the insulation resistance is higher than an ordinary Wheatstone bridge will measure, and the method explained in Article 169 is used.

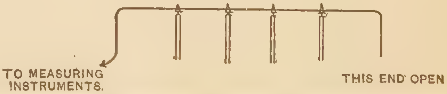

FIG. 310. — Telegraph Line with Ends "Open" for the Purpose of making Insulation Measurements.

The condition of the insulation of a line may also be roughly determined from day to day with the circuit closed. A milliamperemeter is placed in the circuit at one end of the line in series with a battery of a fixed number of cells. If the resistance of the circuit and the pressure of the battery are known, a certain standard current, which may be calculated according to Ohm's Law,[1] should flow through the line when the insulation is perfect. The difference between the current indicated by the amperemeter and the standard current is a measure of the leakage from the line.

A comparison between the recorded periodical measurements of conductivity and insulation shows whether or not the line is in good order, or whether or not any poor connections are developing or its insulation is deteriorating.

**357. Location of a Ground.** — The location of the position of a ground or a cross on a line may be determined in various ways. If the fault is a "dead ground," a measurement of the resistance of the line and ground return is made by "bridge" from one end of the line, the other end of the line being open (Fig. 311); and the distance to the "ground" is calculated at once from the resistance of the line per mile. Thus, suppose a line 500 miles long ordinarily measures 4500 ohms, or 9 ohms per mile, and the resistance measured through a dead ground is 1800 ohms, then the ground is 200 miles from the station where the measurement is made, since 9 times 200 is equal to 1800.

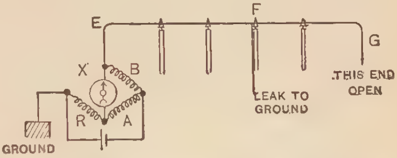

FIG. 311. — Connections of Wheatstone Bridge and Telegraph Line for the Purpose of locating the Position of the "Fault" at *F*.

When the ground is only *partial*, its location is not so simple, since the resistance of the leakage path comes into the measurements. Several methods may be used in making the measurements, but the two following are the simplest. In the first method, the resistance of the line through the **Fault** is measured from each end in the manner illustrated in Figure 311, the far end being open at the time of each measurement. To find the resistance of the line between one end *E*, and the fault, the resistance of the line in good order is added to that measured through the fault from *E*; from this is subtracted the resistance measured through the fault from *G* and the result is divided by 2. For instance, suppose the resistance measured through the fault from *E*, as shown in Figure 311, is 3800 ohms, and a similar measurement made from *G* shows 4700 ohms, the line itself from *E* to *G* measures (as known by previous measurements) 4500 ohms; then the resistance of the line from *E* to the fault is

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[1] Article 92.

$$\frac{3800 + 4500 - 4700}{2} = 1800.$$

If the line measures 9 ohms to the mile, the distance from *E* to the fault is 200 miles.

The reason for this is readily seen, since the total resistance of the line is equal to the resistance from *E* to the fault, added to that from *G* to the fault. The measurement from *E* through the fault gives the resistance from *E* to *F* added to the resistance of the leak. The measurement from *G* through the fault gives the resistance from *G* to *F* added to the resistance of the leak. Adding together the resistance of the whole line in good order and the resistance from *E* through the fault, gives a sum which is equal to the resistance of the leak plus the resistance of the whole line plus the resistance of the part of the line from *E* to *F*. Subtracting the resistance from *G* through the leak leaves a remainder equal to twice the resistance of the line from *E* to *F*.

*Example A*. The resistance of the portion of a line from the end *E* (Fig. 311) to a partial ground is 2000 ohms, from the end *G* is 4000 ohms, and the total resistance of the line is 3800 ohms. If the wire has a resistance of 10 ohms to the mile, what is the distance from the end *E* to the partial ground? *Ans*. 90 miles.

**358. Loop Method for locating Fault.** — The second method of locating a fault is by what is called the **Loop Method**. This can be used only when the leaky wire can be looped with a good wire or the line is a metallic circuit, so that both ends may be connected to a bridge for testing. In this case the connections are made up as shown in diagram in Figure 312, where *DE* is the leaky wire and *CE* is the good one. *AF* makes one bridge arm, and *CF* another, while *AB* and *BC* are the other two arms. When *AD* or *AB* and *BC* are adjusted until the bridge is balanced, the resistance from *C* to *F* and from *A* to *F* are to each other as *BC* is to *AB*, while the total resistance of *CE* plus *DE* plus

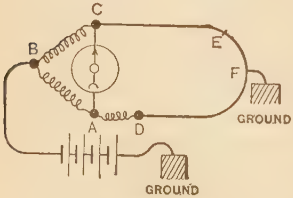

FIG. 312. — Diagram of Connections for locating a "Fault" by Loop Method.

$AD$ are known from the records of the wire conductivities and the reading of the rheostat $AD$. The way in which the connections are made to a post-office pattern bridge is shown in Figure 313.

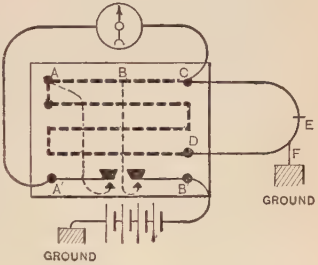

FIG. 313. — Post-office Pattern Bridge applied to Loop Test for locating a Fault in a Telegraph or Telephone Line.

*Example A.* In Figure 312, $AB = 500$ ohms; $BC = 1000$ ohms; $AD = 200$ ohms; $CE = 900$ ohms; and $DE = 400$ ohms. If under these conditions the bridge is balanced, how far from $D$ is the break, supposing the resistance of the line is 5 ohms per mile? (*Aid.* By the proportion of the bridge we have $AB : BC :: AD + DE - EF : CE + EF$; from this it is found that $EF = 100$ ohms.) *Ans.* 60 miles.

**359. Location of a Cross.** — When two wires are crossed, the location of the point where they make contact with each other is carried out in very much the same manner as the location of grounds, except that the measurements are made over a circuit made up of the two crossed wires (Fig. 314) instead of over a circuit made up of the grounded wire and its ground return. The distance from the measuring station to the cross is calculated from the measured resistance and the resistance per mile of the two wires together. Thus, suppose the resistance measured through the cross at $Z$ as shown in Figure 314 is 4400 ohms, and the resistances of the two wires are respectively 9 and 13 ohms per mile. Then the cross is 200 miles from the measuring station, since the resistance per mile of the two wires together is 9 plus 13, or 22 ohms. In this measurement it is assumed that the resistance at the cross itself is too small to be taken into account. When this is not the case, special measurements have to be made, as in the case of a partial ground.

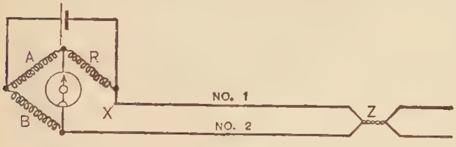

FIG. 314. — Diagram of Connections for locating a Cross in Telegraph or Telephone Lines.

In making test measurements it is usual to disconnect all telegraph or telephone instruments from the circuit, though they may be permitted to remain in circuit and a correction is then made on account of their resistance or insulation.

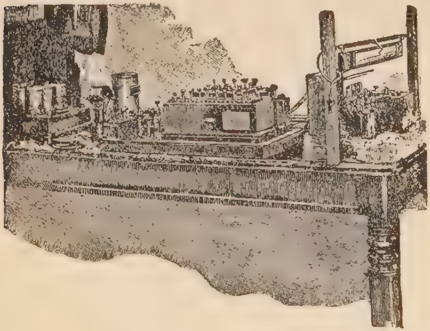

FIG. 315. — Table with Instruments permanently set up for Daily Use at Ocean Cable Station.

**360. Testing Underground Cables.** — In testing underground wires and **Submarine Cables**, practically the same methods are used as in the testing of overhead wires. Systematic periodical tests are quite essential for the preservation of the life of cables, since their usefulness may be quickly destroyed after a leak starts. Figure 315 shows the permanent testing arrangements as they are set up in the testing room at the end of an ocean cable.

**361. Faults in Electric Light and Power Lines.** — The faults which occur in electric light and power lines are of the same character as those which occur in telegraph and telephone lines, but the methods of testing for and locating the faults are very different. The general condition of an electric light line may be determined from the manner in which the lights burn. Breaks in the line are made evident by the fact that lamps on the circuit beyond the break will not burn, while crosses and short circuits soon make themselves evident by causing the fuses which protect the defective part of the circuit to melt or blow. Poor connections may be shown by dimness of the lamps when the connections have a sufficiently high resistance to cause a great drop in pressure. It is needless to say that connections or joints of such poor conductivity are very dangerous, and should not be permitted to exist in a circuit for an hour. *All joints in electric light wires are soldered* in order that there may be no " bad joints " which may cause poor connections.

Poor connections at such points as sockets or fuse blocks belonging to incandescent circuits may cause considerable heating. If such heating is noticed, it should be corrected at once, or it may cause damage.

Sometimes poor connections at fuse blocks may produce heat enough to cause the fuses to blow when there is really no trouble elsewhere on the circuit. This may occur when the fuse blocks have too little contact surface at the connection points to properly carry the current. Such fuse blocks should always be replaced by larger and better ones, as they are not only an annoyance, but are dangerous.

No one would think for a moment of leaving poorly jointed and leaky gas pipes and fixtures in a house, and defective electric wires should be treated in exactly the same manner as defective gas fittings.

**362. Arc-line Testing — The Magneto.** — Series circuits, like arc-light circuits, which are not in use all through the twenty-four hours, are often tested for breaks, grounds, and crosses by means of a "magneto bell," which is very much like a telephone call bell (Fig. 316). The little magneto machine and call bell are put in a box together and connected in series with two terminals on the outside of the box, which are shown at the top of the figure. If it is desired to test the **Continuity** of a line, — that is, the absence of breaks, — the two ends of the line are connected to the test bell terminals. If the bell rings when the crank, which is on the right-hand side of the box (but hidden in the figure), is turned, the circuit is shown to be continuous; while if the bell does not ring, the circuit is shown to be broken, provided the test bell itself is in good condition. It is easy to test the latter by short-circuiting the terminals, when the bell will ring upon turning the crank if the magneto is all right.

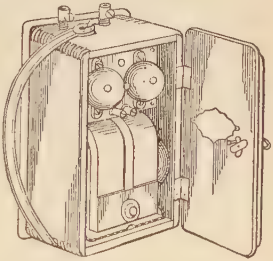

Fig. 316. — Portable Magneto and Bell for Use in Testing.

If it is desired to test for grounds by means of a magneto bell, one terminal of the bell is connected to earth by connecting it through a wire to a gas or water pipe, and the other terminal is connected to the line to be tested. If the bell rings when the crank is turned, this ordinarily means that the line is grounded, and if the bell does not ring, the line is shown to be **Clear** of grounds. Sometimes the bell will ring a little when the line has a very high insulation, because the electrostatic capacity of the line is high, and the current which flows into and out of the line, as it is charged and discharged by the alternating pressure set up by the magneto, is sufficient to ring the bell.

Most arc-light lines are out of use during daylight, — only those which convey current to arc lamps in the buildings of large cities are used during the day, — and many lines are not used after midnight. It is quite convenient, therefore, to use the magneto bell for testing such lines. The tests can be made an hour or two before the lines come into service each day, and if anything is found to be wrong, a lineman can go along the line to find the trouble and fix it.

**363. Testing Arc Circuits by Voltmeter or Incandescent Lamps.** — A voltmeter is sometimes used for testing and locating grounds on arc-light lines while they are in use. Suppose that Figure 317 represents an arc-light line which supplies current to 11 lamps, and is grounded at *F*. If the lamps are so adjusted that each requires 45 volts pressure, the difference of pressure between the fault and one terminal of the dynamo is 270 volts, and between the fault and the other terminal of the dynamo the difference of pressure is 225 volts. A voltmeter connected to ground, as shown in Figure 317, indicates the difference in pressure between the fault and one dynamo terminal, and so shows between what lamps the fault is located.

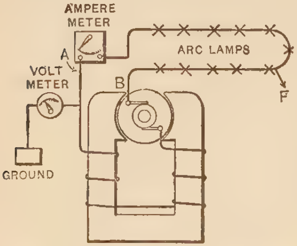

FIG. 317. — Testing the Insulation of an Arc-light Circuit by a Voltmeter.

Instead of using a voltmeter, 45-volt incandescent lamps may be used for testing by this method. As many 45-volt incandescent lamps are connected in series as there are arc lamps on the circuit to be tested. One end of the series is connected to ground, and the other to one dynamo terminal. Then one incandescent lamp after another is short-circuited until the lamps which remain in the circuit burn to their full candle power. The number of incandescent lamps then in circuit is equal to the number of arc lamps between the dynamo terminal and the fault. The reason for this is evident upon examining the figure. Since there are six arc lamps between the *A* terminal of the dynamo and the fault, there is a difference of pressure of 270 volts between the two points, as shown by the voltmeter. Two hundred and seventy volts is the pressure required to bring a series of six 45-volt incandescent lamps to full candle power, so that the number of arc lamps between the fault and the *A* dynamo terminal is equal to the number of 45-volt incandescent lamps which will burn with full candle power when connected in series between the dynamo terminal and the ground. This test is made upon the supposition that the fault has little resistance in itself.

*Example A.* A circuit containing 10 arc lamps, each adjusted to burn with a pressure of 50 volts, is so grounded that when a voltmeter is connected between one terminal and the ground the reading is 200 volts. Between which two lamps is the location of the ground, counting from the terminal to which the voltmeter is connected? *Ans.* Between the fourth and fifth.

**364. Testing Constant Pressure Circuits — The Ground Detector.** — In testing incandescent lighting circuits for grounds, incandescent lamps or voltmeters are almost always used. If one wire of a two-wire circuit is grounded, the presence of the ground may be shown by connecting an incandescent lamp between the other wire and the earth (water pipes, etc., Fig. 318), when the lamp will burn on account of the current which flows from one wire to the other through the lamp and the fault. If the lamp is intended for the same pressure as that of the circuit, it will burn at full candle power if the circuit is "dead grounded," and will be dimmer in proportion to the resistance of the fault.

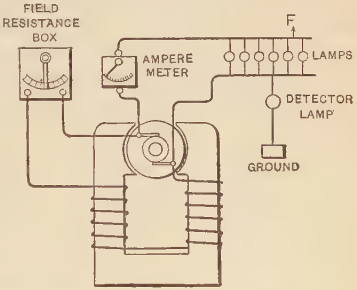

FIG. 318. — Incandescent Lamp used as a "Ground Detector."

Figure 319 shows a permanent arrangement of the **Ground Detector**, which is fixed so that the detector lamp may be connected at pleasure with either of the wires.

Another arrangement of lamps for a ground detector is shown in Figure 320, where *A* and *B* are two lamps connected in series between the two wires of the electric lighting system. A wire goes to ground through a fuse block and a switch from a point between the two lamps. When the switch is open, the lamps *A* and *B* burn very dimly, but of equal brightness, and no change occurs when the switch is closed if no grounds are present on the circuit. But if the wire to which the *A* lamp is connected becomes grounded, current will flow from the grounded wire through the *B* lamp to the other wire when the switch is closed, and the *B* lamp will become brighter than the *A* lamp. In the same way the *A* lamp will brighten when the switch is closed, if the *B* wire is grounded. Sometimes both wires are grounded, and the faults have about equal resistance. In this case the lamps will not show the grounds in the ordinary way, but the test can be made by turning off one lamp when the switch is closed, and the other lamp will go out if the circuit is not grounded.

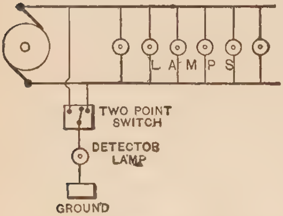

FIG. 319. — Incandescent Lamp used as a "Ground Detector."

When high pressures are used, too many lamps would be required, so that a differential galvanometer or equivalent device is used as a ground detector. The differential galvanometer consists essentially of two equal coils, one over the other, which surround a suspended magnetic needle. The coils are connected to the circuit in series, and with a ground connection between them just as the lamps are connected, but their magnetic effects on the needle are in opposition. When there is no ground, the needle stands at zero; but when there is a ground, the magnetic effect of one of the coils becomes stronger, and the needle is deflected. For very high pressures, electrostatic ground detectors are frequently used. An electrostatic ground detector is illustrated in Figure 321. It consists essentially of a quadrant electrometer with one quadrant connected to each side of the circuit, and the other two connected to the needle and to ground. The needle stands at zero when

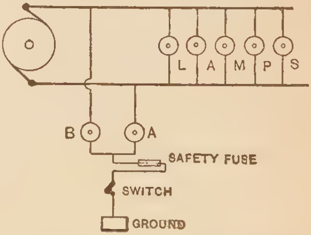

FIG. 320. — Ground Detector with Two Incandescent Lamps and Ground Connection between them.

neither side of the circuit is grounded, but moves to one side or the other if one wire or the other becomes grounded.

For three-wire circuits[1] a pair of lamps may be used as a ground detector for each side of the system.

When a voltmeter is used to test for grounds on an incandescent circuit, it is employed in very much the same way as the incandescent lamp which is used for the same purpose. The voltmeter is connected between one of the circuit wires and the earth. If the other wire of the circuit is grounded, current will flow from it through the ground to the voltmeter, and through it to the wire to which the instrument is connected. If the grounded wire is "dead grounded," the voltmeter will give the same reading as when it is connected directly between the wires. The reading of the voltmeter is less as the resistance of the ground contact is greater, and it is zero when the insulation is perfect.

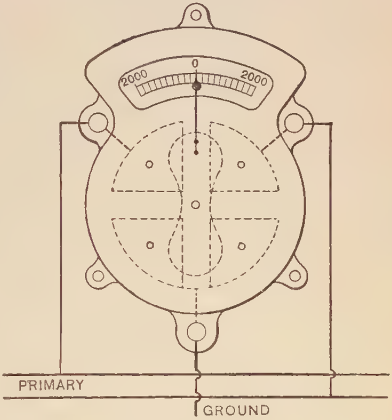

FIG. 321.— Electrostatic Ground Detector.

**365. Locating Grounds on Electric Light Wires.** — The methods which are used for testing for grounds on incandescent circuits show when a ground is present and upon which wire it exists, but they do not give any clew to the particular portion of the circuit upon which the ground is located. The ordinary method of "locating" a ground which cannot be found by inspection is to cut one branch after another off from the system until the ground disappears. The ground is then on the last branch cut off, and may be found by careful inspection. If the wires are not being used, the testing of the branches may be done by the use of a magneto, as in arc lighting. When buildings are newly wired, all lines should be carefully tested by a magneto for breaks, crosses, and grounds, and then careful insulation measurements with instruments should be made before closing the dynamo switches.

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[1] Article 334.

The testing and locating of faults in lead-covered cables which are sometimes used in underground systems is done in the same way as the insulation testing of telegraph and telephone cables, which has already been explained.[1]

**366. Measurement of Candle Power.** — The candle power and the best arrangement of the lamps which are required to give a satisfactory illumination in any particular space can be determined only by experience. The candle power of lamps is measured by an instrument called a photometer, in which the illuminating power of the lamp to be measured is directly compared with the power of **Standard Candles,** or with a gas jet or lamp of known candle power. Standard candles are made of sperm wax; their wick is a very carefully made cotton braid; and candles of full length (ten inches) weigh one-sixth of a pound apiece. Each candle should burn with a consumption of wax at the rate of 120 grains consumed per hour. These candles should not usually be snuffed. In Germany, candles of somewhat different character are used.

The commonest form of a photometer is that called Bunsen's photometer, which is shown diagrammatically in Figure 322. The standard candle is shown at *A*, the lamp whose illumination is to be measured is at *B*, and *D* is a movable disk of thin paper with a grease spot at its centre. The photometer must be enclosed in a perfectly dark closet for satisfactory use, and the light from *A* and *B* is carefully screened on every side except directly in line with the disk. An observer measures the unknown candle power of the lamp *B* by moving the disk *D* until it shows an equal illumination on both sides. The disk is generally looked at by means of mirrors, so that both sides may be seen at once.

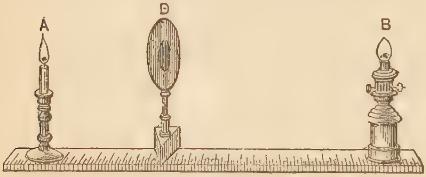

FIG. 322. — Simple Bunsen Photometer.

When the illumination of the two sides of the disk is equal, *the candle*

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[1] Articles 356 to 359.

*powers of the lights are related to each other in the ratio of the squares of the distances measured from the respective lights to the disk.*

*Example A.* *A* in Figure 322 is a standard candle, and *B* an electric light, the candle power of which is to be measured. If the distance from *A* to the screen is 20 inches, and from *B* to the screen is 80 inches, what is the candle power of the electric light? *Ans.* 16 c.p.

**367. Light varies inversely as the Square of the Distance.** — The reason that the squares of the distances come into the comparison of candle powers is illustrated in Figure 323. If we suppose a screen, *AB*, to be placed at a distance of one foot from the lamp, *L*, we may consider that the screen is illuminated by a certain number of rays of light falling upon it. Now, if the screen is moved to a distance of two feet from the lamp, the same rays of light will illuminate an area *CD*, which is four times as large as *AB*, and consequently the intensity of the illumination of the screen is only one-fourth as great as when the screen was at a distance of one foot from the lamp. If the screen is moved to a point three feet from the lamp, the same rays will cover the area *EF*, which is nine times as large as *AB*, and the intensity of the illumination is only one-ninth as great as when the screen was within a foot of the lamp.

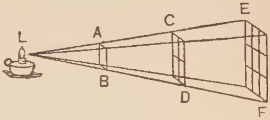

FIG. 323. — Illustration of the Variation of Illumination in Inverse Proportion with the Square of the Distance from a Lamp.

Since four and nine are respectively equal to the squares of two and three, we see that *the intensity of the illumination given to a surface by a fixed light is inversely proportional to the square of the distance from the light to the surface.*

In the Bunsen photometer the screen is placed at such a point directly between two lights that they illuminate it equally. In this case the lights must have candle powers which are proportional to the squares of their distances from the screen, as already said.

**368. Distribution of Lights.** — The actual illuminating effect of a given number of lamps in any space depends upon a great many things. For instance, a room with dark walls, which absorb a great deal of light, requires much more light to give a satisfactory illumination than does a room with light-colored or white walls. In a comparatively small space a number of lamps of small candle power, properly distributed about the space, usually give a more satisfactory light than do a few large lamps giving the same total candle power. This is because the illumination near the large lamps is very great, and at other points in the space the illumination is small, while it is much more evenly distributed by the small lamps.

In ordinary rooms and stores it is common to put from one to three 16-candle-power incandescent lights for each hundred square feet of floor, while in larger rooms 450-watt enclosed arc lamps may be used so that each arc illuminates from 500 to 1000 square feet of floor space. The incandescent lights should be suspended in such a way as not to be more than eight feet from the floor, and be provided with reflectors or shades. If the lamps are placed higher, proportionately more lights must be used.

Where arcs are placed indoors, it is usual to surround the arc with an opal glass globe, which distributes the light more satisfactorily than would otherwise be the case. Such globes have the disadvantage of absorbing nearly one-half of the light of the arc, but their effect in distributing the light is sufficiently important in indoor lighting to counterbalance the loss of light. Arc lights should be placed higher from the floor than is usual for incandescents. For outdoor lighting open arc lights with clear glass globes have been ordinarily used, but "enclosed" arc lamps, with opalescent inner globes and clear glass outer globes, are now rapidly coming into general use.

Street lamps (arcs) are placed from 50 to 600 feet apart, depending upon the amount of illumination desired. It is an important fact, which is not very well known by electric light companies, that dirty globes of clear glass may absorb even more light than do opal globes, and in the case of the inner globes of the enclosed lights it is not unusual for the light to be reduced to a mere glow by a little inattention, so that it is important that arc-light globes be kept clean. If the "enclosed arc" lamps are carelessly trimmed, carbon dust rapidly collects and is burned into the glass, which often makes the globe almost opaque.

**369. Measure of Illumination — The Candle Foot.** — It may be seen from what precedes that the true measure of illumination is not the candle power of a lamp, but it is the amount of light or **Illumination** obtained on a surface which is illuminated by the lamp. *The unit for* *measuring illumination is the intensity of illumination on a perpendicular screen at the distance of one foot from a lamp which gives one candle power.*

Four candle power at a distance of two feet from the screen, and nine candle power at a distance of three feet from the screen, give the same illumination as one candle power at a distance of one foot from the screen. This illumination is called a **Candle Foot.**

*The illumination (in candle feet) given by any lamp upon a perpendicular surface is equal to the candle power of the lamp divided by the square of the distance between the lamp and the surface.* For instance, if we have a 32-candle-power lamp at a distance of 6 feet from a wall, the illumination on the wall is 32 divided by 6 squared (or 36), which is equal to about .9 of a candle foot ($\frac{32}{36} = .889$).

*Example A.* An incandescent lamp is 4 feet from a reading book. How much illumination will it give for reading, if the lamp gives 16 candle power in the direction of the book? *Ans.* 1 candle foot.

*Example B.* An arc lamp gives 800 candle power in a certain direction. What will be the illumination from it at a distance of 200 feet in that direction? *Ans.* $\frac{1}{50}$ of a candle foot.

An illumination of one candle foot is rather poor for ordinary reading, but an illumination equal to from two to three candle feet is very satisfactory, especially if the direct view of the lights does not meet the eyes and so reduce their sensitiveness. Ordinary bright moonlight gives an illumination on the ground which is equal to about $\frac{25}{1000}$ of a candle foot. The illumination upon theatre stages is ordinarily from three to four candle feet, and the illumination given by diffused daylight is equal to from ten to forty candle feet. On account of the expense of producing artificial light by the common methods of the present day, it is commercially impracticable to artificially produce as great an illumination as may be given by daylight.

A handy plan for roughly comparing the illumination in various situations is the following: A cubical box, six or eight inches on a side, and without a cover, should be blackened on the inside and a piece of newspaper placed in its bottom. The ease with which the words on the paper may be read when looking into the box with shaded eyes gives a rough and ready determination of the quality of the illumination at the spot occupied by the box. By moving around a room with the box, a rough determination of the uniformity of the illumination in the room, and therefore of the correctness of the locations of the individual lights, may be made. By taking the box from room to room or building to building, a rough comparison may be made of the illumination at different places. A special photometer, by means of which such comparisons may be made with great accuracy, is called a Weber photometer. The actual illumination at any point may be directly measured in candle feet by means of this instrument. Figure 324 shows a Weber photometer ready to measure the illumination on a library reading table.

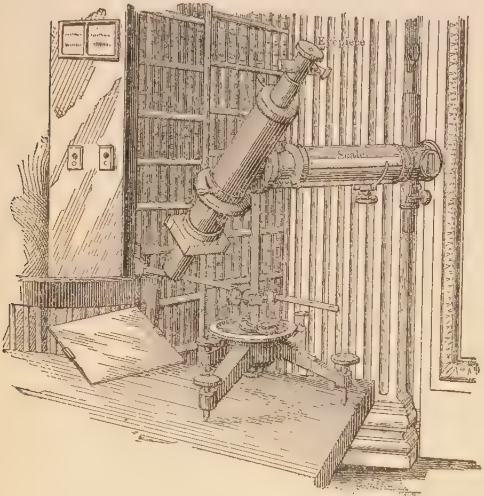

FIG. 324.— Weber Photometer standing on Reading Room Table.

It must be remembered that it is not always desirable to have a perfectly uniform illumination in a room, but is often necessary to have a high degree of illumination at certain points. In library reading rooms, for instance, the reading tables should be most highly illuminated. In picture galleries, the pictures should have a strong light thrown on them. In theatres it should be possible to vary the lights, and also be possible to throw an intense illumination upon any part of the stage. On the other hand, schoolrooms, drawing-rooms, ballrooms, and other like rooms should ordinarily be provided with illumination that is as nearly uniform as possible.

## QUESTIONS

1. What are the classes of trouble that occur on telegraph and telephone lines?
2. What is a ground? A cross?
3. How can the position of trouble on a telegraph line be located?
4. How does trouble usually become apparent on telephone lines?
5. What is cross talk? How can it be avoided?
6. How is the conductivity of a long line measured?

7. How may the conductivity of three parallel wires be measured?

8. What are earth currents?

9. How may the insulation of a long line be measured?

10. How can a "dead ground" be located?

11. How can a partial ground be located by taking measurements from either end of the line?

12. What is the loop method of finding a ground?

13. How can a cross be located?

14. What faults occur in electric light circuits?

15. How do faults in electric light circuits make themselves evident?

16. Why does safety require that the joints in electric light wires shall be soldered?

17. What is a testing magneto?

18. How can arc circuits be tested for continuity and grounds by a magneto?

19. How may a fault be located on an arc circuit by a voltmeter? By incandescent lamps?

20. What is a ground detector? On what kinds of circuits is it used?

21. How does a ground detector with one lamp work?

22. Why does one of the lamps brighten in a two-lamp ground detector when there is a ground on one wire?

23. How may a voltmeter be used for testing for grounds on incandescent circuits?

24. If one wire of a circuit is dead grounded, what will be the readings of the voltmeter when connected from the ground, first to the grounded wire, then to the other wire?

25. How are grounds or crosses located on constant potential circuits?

26. Can a magneto be used in testing constant potential circuits?

27. Tell how you would test for continuity and grounds in a building that had just been wired for incandescent lamps. How would you test for insulation resistance?

28. What is a photometer?

29. What is a standard candle?

30. How may the intensity of two lights be compared by a photometer?

31. Why does the intensity of illumination vary inversely as the square of the distance from the light?

32. What is the effect of the color of the walls and the size of the light upon the distribution in a room?

33. What is the effect of opal shades or globes upon the light from a lamp? Of dirty globes?

34. What is the candle foot?

35. How does the intensity of illumination in candle feet vary with the distance from the light?

36. What intensity of illumination is desirable for reading?

37. What is the intensity of illumination of moonlight? Of sunlight?

38. How can you roughly compare the illumination in various parts of a room?

# CHAPTER XXII

## ELECTROLYTIC DEPOSITION OF METALS
## ELECTRIC SMELTING, WELDING, COOKING, ETC.

**370. Commercial Electrolysis.** — The electrochemical operations which result in depositing metals from solutions of their metallic salts are very widespread in the industries, and are of great usefulness. The magnitude of the works involved in most of the operations does not approach that of works built for the purpose of furnishing electricity for light and power; nor do the ordinary electrolytic operations appeal to the ordinary observer as do the applications of electricity to transmitting messages, driving street cars, or furnishing light or power. Nevertheless, we owe to electrochemical operations many of the commonest necessities of life. The commercial applications of electrolysis cover a wide and useful range, from nickel and silver **Plating** to **Electrotyping** for the use of the printer; and from methods of **Bronzing** and **Gilding** to methods of **Smelting** certain ores and **Refining** metals. Electrolysis is also becoming a most important factor in chemical manufactories. At Niagara Falls alone not less than 10,000 horse power is utilized in manufacturing bleaching powders and other commercial chemical products. Nearly all of the processes depend upon the laws of chemical action which have already been described in Chapters IV and V; but the solutions used are frequently quite complex, so that the chemical action which occurs is complicated and not always fully understood.

A working knowledge of the processes of electro-deposition of metals has been possessed only since 1800, and indeed many of the more important processes of electroplating, electrotyping, etc., have been discovered since 1840 or 1845, while some of the important operations of electrometallurgy, such as the electrolytic recovery of aluminum and the commercial refining of copper by electrolysis, have not been employed until within a very few years. The next few years seem destined to see electrolysis and electrometallurgical processes (processes of treating metals in which electricity is used) put into extended use in the recovery of various metals from their ores, and in some hitherto little explored fields, such as the purifying of drinking water and **Sterilizing** of sewage.

**371. Electroplating ; Silver Plating. — Electroplating** is the process of covering articles of metal with a thin layer of another metal by means of electrolysis from a solution containing a salt of the deposited metal. The covering usually consists of nickel, silver, or gold, and the base, or covered metal, is ordinarily of some composition, such as white metal, Britannia metal, German silver, or brass.

The details of the processes are quite different for the different metals used in plating. We will first consider silver plating, as silver is the most important metal in plating processes.

The commonest salts of silver are chloride of silver, nitrate of silver, cyanide of silver, and acetate of silver. A salt of a metal is a chemical combination formed by the action of an acid on the metal. Thus, nitrate of silver is formed by the chemical action of nitric acid upon silver. Nitric acid is a chemical combination of hydrogen with oxygen and nitrogen, the oxygen and nitrogen in this case forming what is called an *acid radical.* The radical of nitric acid has a greater chemical attraction or *affinity* for silver than for hydrogen. Consequently, when silver is immersed in nitric acid, the silver is attacked and dissolved, during which process it combines with the acid radical and forms nitrate of silver, while the hydrogen of the acid is given off. The salts of silver which are used in electroplating are usually made from the nitrate. The nitrate of silver is produced by adding pure silver, in small quantities at a time, to a warm mixture of one measure of *distilled water* to four measures of pure, strong nitric acid. The action of the acid upon the silver is very intense and causes much heat to be given off,[1] and if the mixture is too hot, or too much silver is added, the liquid may boil over. In this case the mixture may be cooled by adding a little cold distilled water. When the mixture will dissolve no more silver, the solution may be put in a covered jar and set in a dark place until it is required for use.

A properly diluted solution of nitrate of silver is used with a silver voltameter,[2] but the deposit from a nitrate solution does not make a satisfactory plating. The best silver-plating solution is one containing *cyanide of silver.* Cyanide of silver is the salt formed by the combination of silver with prussic acid. A solution of cyanide of silver is formed by slowly adding to the silver nitrate solution, made substantially as already described, a weak solution of cyanide of potash, or white prussiate of potash, as it is often called. The cyanide of potash should be dissolved in about ten times its own weight of distilled water. The addition of the potash solution to the nitrate of silver solution should be continued as long as a white **Precipitate** forms, but no longer, or some of the silver is lost. The precipitate which forms is cyanide of silver. This should be allowed to settle, after which the clear liquid may be carefully poured or drawn off. The precipitate is then washed a number of times by pouring distilled water over it and stirring, allowing the precipitate to settle and pouring off the liquid.

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[1] Compare the action of sulphuric acid upon copper, Article 60.

[2] Article 158.

Cyanide of silver does not dissolve in water, but readily dissolves in a solution of cyanide of potash in water, and silver-plating solutions are usually made by so dissolving the silver cyanide. Cyanide solutions are extremely poisonous, and therefore must be handled carefully; and on account of the value of the silver which they contain, must be handled without waste.

**372. Vats for Silver Plating.** — The vats in which silver plating operations are carried out are usually made of wood, though they are sometimes made of sheet iron lined with wood. They are of various dimensions, but generally are from two to three feet wide, five to six feet long, and about thirty inches deep. When the solution is made up and put in the vat for service, it usually does not require changing for a number of years. It sometimes requires filtering, and the addition of water to supply that lost by evaporation or the addition of cyanide salts to supply losses which have come about

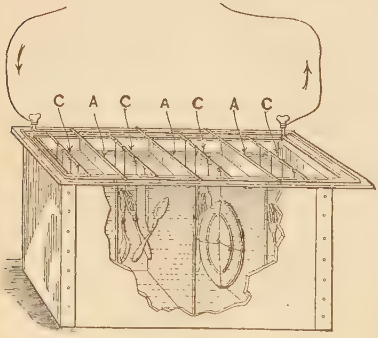

FIG. 325. — Silver Plating Vat with One Side cut away so as to show the Articles in the Solution. *A*, *A*, *A*, Supports for Anodes. *C*, *C*, *C*, *C*, supports for Cathodes.

by electrolysis. The exact proportions of the solution used for silver plating in different factories vary considerably, but they are nearly always substantially as already described.

The general arrangement of a plating vat is shown in Figure 325, where the flat plates inside the vat are sheets of silver which are connected to the positive pole of the source of current and form the anodes of the electrolytic cell,[1] while the spoons, forks, and other articles to be plated form the cathodes. The supports for the anodes and cathodes are usually made of brass or copper tubes laid across the top of the vat.

The articles to be plated are ordinarily supported on looped pieces of insulated copper wire (Fig. 326). The insulation of these supports where they are immersed in the liquid is important, in order to avoid an unnecessary and expensive deposit of silver upon them. The silver deposit made on the cathodes occurs as a result of electrolysis, and an equal amount of silver goes into the liquid from the anodes when all is working well.[2]

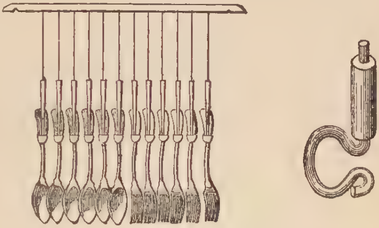

FIG. 326. — Method of supporting Spoons and Forks in Silver Plating Vat.

**373. Pressure and Current.** — The quality of the deposit which is made in electroplating is of the first importance. The three points to be looked after most carefully are: the strength of the current as compared with the magnitude of the surface to be plated; the composition, density, and temperature of the plating solution; and the condition of the articles to be plated when put into the solution. The current for plating was formerly furnished by batteries, but it is now ordinarily furnished from small dynamos which produce a low pressure properly adapted for the purpose. The pressure may also be adjusted to a considerable extent by means of a resistance box connected in a circuit with the magnetizing coils of the dynamo. The current and pressure supplied by the dynamo may be measured by means of an amperemeter and a voltmeter.

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[1] Article 59.

[2] Article 60.

One dynamo of sufficient size may be used to supply current to several plating vats. The vats may be connected either in series or in parallel, depending upon the pressure developed by the dynamo. When the current is of the proper amount, the silver covering which is deposited upon the plated articles is hard, white, adheres closely, and is deposited with reasonable rapidity. When the current is too small, the deposit is usually of good quality, but the plating progresses too slowly. When the current is too great, the plating is likely to become gray or black and rough, while gas is sometimes given off at the cathodes. A discoloration of the silver deposit may also occur from impurities in the liquid. Such discoloration may often be removed by proper "after treatment" of the plated articles, but to this attention cannot be given here.

**374. Relative Positions of Anodes and Cathodes.** — The form of the articles to be plated often has much to do with the quality of the plating. Thus, bulky articles with a given surface often cannot be plated as rapidly as flatter articles with exactly the same amount of surface to be covered. Edges and points often gather a granular or rough deposit, while the flat parts of the same articles take a satisfactory, hard deposit. Such difficulties can be overcome only by making a proper mutual adjustment of the distances between anodes and cathodes, the quality of the liquid, and the current per unit surface of the articles. When articles which have great irregularities of surface are to be plated, the distance between anodes and cathodes must be greater than that which is satisfactory when the articles have a uniform surface, otherwise the more prominent points of the articles will receive a heavy deposit while the hollows may receive little or no deposit. It is important that all plated articles be given a uniform deposit of proper thickness upon the surfaces which are desired to be covered. The thickness of silver plating ordinarily varies from the thinnest possible coating to the thickness of thin writing paper, depending upon the quality of the product.

There is a method of plating by simply dipping the articles in a proper silver solution which is used to silver small articles such as hooks and eyes, on which the coating is too thin to be really measured. In this case the plating is not due to electrolytic action, but simply to chemical action between the silver solution and the metal composing the articles to be covered. This is called *plating by simple immersion.*

**375. Preparation of Material for Silver Plating.** — In preparing articles for silver plating, the greatest care must be taken to make them *absolutely clean* and bright, or the plating will not take a permanent hold, but will peel off. It is first necessary to prepare the articles for the kind of coating they are intended to receive; if the plating is intended to be polished, the articles must be polished, all deep scratches must be removed, etc. This may be done by filing, scouring, polishing, etc. After this preparation, the cleaning is begun by dipping in a warm solution of caustic potash or soda which cleans off all grease. This solution is made by dissolving commercial lye in water, and it may be used continuously until its caustic properties are used up.

After dipping in lye the articles are washed in water and are then sometimes dipped in dilute acid to give them a proper surface. They are next washed with great care and then placed in the depositing vat. It is quite common to cover articles to be silver plated with a very thin coating of mercury. The object of this is to avoid oxidation of the articles, which causes the plating to peel. Coating with mercury is called **Quicking**, and it may be effected by dipping the articles into a dilute solution of nitrate of mercury, or the solution of some other mercury salt.

During the operations of dipping, the articles should be supported upon wires or in wire baskets. They should not be touched with the fingers, since the points so touched are made greasy, and the deposit will not **Take**.

**376. Buffing and Polishing.** — After the plating is completed in the bath the articles must be put through a series of operations to give the plated surface the proper finish. This is largely done by polishing on rapidly revolving wheels made of brass wires, leather, and canvas. The processes are called **Scratching, Buffing,** and **Polishing.** The same tools are used for polishing the articles before plating. In the case of some articles, the polishing is done by means of hand **Burnishers**, which are smooth tools made of steel, agate, or similar hard materials. Some forms of burnishers are shown in Figure 327.

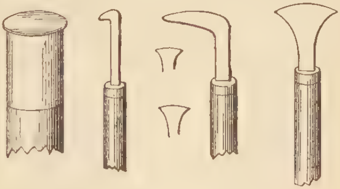

FIG. 327. — Several Forms of Steel Burnishers.

**377. Gold Plating.** — Plating with gold is carried on in very much the same way as plating with silver. The commonest solution is of cyanide of gold made up in a manner quite similar to that used in making up the cyanide of silver solution. The solution is generally used when hot, and great care to have all the details exactly right is necessary to get a deposit of satisfactory color. It is particularly important that all the materials used in making the solution shall be pure.

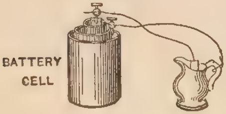

FIG. 328. — Arrangement of Circuit for Gilding the Interior of a Metal Cream Pitcher.

Gilding the inside of silver cups, sugar bowls, and cream pitchers is commonly done by filling the article to be gilded with the hot solution, hanging a gold anode in the shape of a cylinder in the centre of the solution, and finally connecting up a battery so that the article to be gilded is the cathode (Fig. 328). The extreme cleaning of articles for gold plating is usually not as important as in silver plating, since the hot solution helps in the cleaning.

**378. Nickel Plating.** — Nickel plating is probably the most generally used of all the different styles of plating. The base upon which nickel is plated is usually brass, copper, iron, or steel. The soft white metals which are often silver plated are seldom nickel plated. The hardness of nickel and its durable polish give to nickel plating great advantages for use in the finish of sanitary appliances, car fittings and decorations, small nuts, bolts, screws, chains, etc., used in small machinery, bicycles, stove fronts, metal lamps, and many similar appliances.

The solution which is used in nickel plating is made from a combined sulphate of nickel and sulphate of ammonia. In a dry state, this is ordinarily known as *nickel salts* or the *double sulphate of nickel and ammonia*. This double salt may be purchased in the market. In order to make a nickeling solution, the pure salt, which comes in green crystals, is obtained, and is dissolved in hot water at the rate of about three-quarters of a pound to a gallon of water. The vat used to hold a nickeling solution is usually of wood lined with lead. The joints in the lead lining are

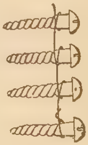

FIG. 329. — Screws prepared for suspending in Nickel Plating Bath.

burned together, not soldered. In the preparation of articles for nickel plating, they must be very carefully polished and cleaned by scouring, dipping in a hot lye solution, and pickling in acid. The latter is very important, since the acid takes off from the articles the thin covering of oxide which is likely to stick to iron, copper, and brass, and which the nickel solution has no tendency to remove. If the oxide covering is not removed, the nickel plate will come off, or **Strip**, as it is called, while the articles are being burnished. The final processes of nickel plating are polishing and burnishing.

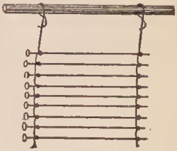
FIG. 330. — Bicycle Spokes prepared for suspending in Nickel Plating Bath.

Articles to be plated with nickel are hung in the liquid or **Bath** very much as already described under silver plating. When a number of small articles are to be nickel plated they are often suspended in a string from the same wire. Figure 329 shows the manner of suspending screws in the nickel bath, and Figures 330 and 331 show the manner of suspending bicycle spokes and chains.

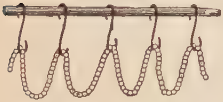
FIG. 331. — Small Chain prepared for Nickel Plating Bath.

Figure 332 shows the form of a vat generally used in nickel plating. Nickel plating vats are generally larger than those used in silver plating. It is particularly important that no *organic* (non-metallic) impurities be allowed in a nickel bath, as these ruin the quality of a nickel deposit.

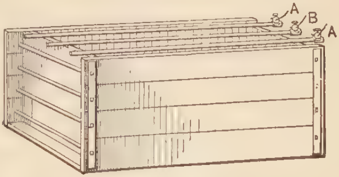

FIG. 332. — Nickel Plating Vat. *A A*, Rods from which Nickel Anodes may be suspended; *B*, Rod from which Articles to be plated (Cathodes) may be suspended.

**379. Electrotyping and Copper Plating.** — **Electrotyping** is a process of reproducing type and woodcuts and other illustrations by means of an electroplating of copper, which is used in nearly all large printing establishments. In electrotyping, an **Impression** or mould is made of the type, which is set up as for printing. This mould is usually made in wax or soft paper pulp by pressing it hard upon the type. After the surface of the mould is properly trimmed it is coated with fine plumbago or some similar conductor, which is carefully brushed over it, so that an electrolytic shell of copper may be deposited upon it.

The **Plumbagoing**, as it is called, is necessary because the mould itself is a non-conductor, and the current which is necessary to make an electrolytic coating cannot be sent through it. Plumbago is powdered graphite, and is a fairly good conductor,[1] so that a thin coating brushed over the surface of the mould enables it to conduct the current. Thus prepared, the mould is hung in an electrolytic bath, consisting of a solution of sulphate of copper (blue vitriol) to which a small percentage of sulphuric acid is added. The anode of the electrolytic cell is a plate of copper, and the cathode is the mould. The thickness of the shell of copper which is deposited on the mould varies from that of a sheet of the paper upon which this book is printed to several times that thickness, depending upon how much printing is to be done from the electrotyped **Plates.**

When the copper deposit is of proper thickness, the mould is removed from the bath, and the copper shell is separated from the mould. The shell is then trimmed, and finally "backed up" by a filling of type metal, which is melted and poured upon the back of the shell. Electrotyped plates have a great advantage over type, in having a permanent form and in wearing much better. As soon as the mould for electrotyping is taken off from set-up type, the type may be distributed and used again.

Copper plating is also sometimes used to give a bronze finish to iron lamp-posts, gas fixtures, etc., and it is used to make a foundation coating upon iron articles which it is desired to silver plate. The solution which is used for this purpose is usually the same as that used for electrotyping.

**380. Plating with Other Metals.** — Plating with other metals than those referred to above, such as iron, tin, or zinc, is sometimes carried out for special purposes. These require special solutions and peculiar care in handling the articles to be plated. It is even possible to electrolytically deposit brass, german silver, or other alloys. These require extreme care, however, in the management of the solutions and the regulation of the electric pressure and current supplied to the vats.

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[1] Article 7.

Zinc plating has come into considerable vogue of late years as a substitute for **Galvanizing**, in which articles are covered with a zinc coating by dipping them in a bath of melted zinc.

**381. Refining Copper.** — A very useful application of electrometallurgy is the refining of copper. In this operation the **Crude Copper** which comes from ordinary smelting works with from two to five per cent of impurities is refined by electrolysis so that only very minute amounts of impurities remain. We have already seen[1] the effect of impurities in reducing the electrical conductivity of copper and other metals. When the electrolytic method of refining copper is properly carried out, it leaves such a small amount of impurities that the **Electrolytic Copper** has almost as great conductivity as pure copper.

Copper wires to be used in electric lighting and in the manufacture of electric machines are therefore generally made of electrolytic copper. It is usual for such wires to have more than 98 per cent of the conductivity of pure copper. The small amount of impurities which do remain in electrolytically refined copper is largely composed of silver and iron.

In electrolytic refining, the crude copper is cast into heavy plates which are used as anodes in depositing vats. The solution in these vats is copper sulphate with a little sulphuric acid. The cathodes at first are thin sheets of pure copper, but they grow by deposition into thick plates of copper which may be worked into bars and drawn into wires as desired. The action in the depositing vats is quite similar to that which goes on in a copper voltameter.

Enormous dynamos are used in copper refining works, and a great number of tanks or vats, each containing a number of anodes and cathodes which are arranged in alternate rows, are provided. The vats are ordinarily connected in series, or sets of a number of vats connected in series are connected in parallel with each other. The several rows of anodes in each vat are connected in parallel, as are also the cathodes. The pressure required to pass the current through each vat is quite small, and consequently a number of vats may be connected in series without causing the total pressure to exceed 100 volts.

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[1] Article 91.

It is desirable that the pressure required at each vat be as little as possible, in order to avoid the deposition of impurities on the cathodes, and also to save power. The power used in each vat is equal to the difference of pressure between the anodes and cathodes multiplied by the current flowing through the vat.

It is desirable to have as great a current flow as will give a fairly smooth deposit, in order that the time required in depositing each pound of copper may be as small as possible. Any reduction made in the current without changing the pressure simply reduces in a proportional rate the amount of copper deposited per hour, so that the power required to deposit a pound of copper is not materially changed. If the pressure required to pass the current through the vats is reduced without changing the current, it at once reduces the power required to deposit a pound of copper, and a saving in the cost of manufacture is effected. In order to reduce the pressure the anodes and cathodes are set as closely together as possible without interfering with the circulation of the solution.

During the process of refining copper by this means the impurities of the crude copper are mostly dissolved in the solution or are thrown to the bottom of the vats as mud or **Sludge**. Copper that is to be electrolytically refined usually contains some silver and a little gold. During the refining process these form salts, which become part of the mud, and the precious metals are recovered by the ordinary method of smelting when the mud is removed from the vats. Iron and lead are also contained in the crude copper, as are smaller quantities of other metals. The lead goes to the bottom of the tank like the gold and silver, and the iron dissolves in the solution, but is not deposited on the cathode except in very small amounts unless the pressure at the vat is too high. Electrolytic refining of crude copper from ores which contain silver is particularly useful, because it is the cheapest method of separating the silver from the copper. Great electrolytic refineries, therefore, have been erected at the Montana copper mines, the ores of which usually contain a valuable portion of silver.

**382. Refining Other Metals.** — Electrolysis has been applied to the refining of other metals, but without great success. It has also been used in the recovery of precious metals from their ores, but thus far without much success, although there is every reason to believe that it may ultimately prove of value in working certain kinds of ores.

**383. Electrolytic Reduction of Aluminum.** — A most important joint application of electric heating and electrolysis is now used in the production of the valuable metal aluminum. The compounds of this metal compose an amazing proportion of the material of the earth's crust; they exist in the forms of clay, marl, slate, feldspar, mica, corundum, and many other mineral forms which go to make a part of the rock material of the earth. These compounds contain goodly proportions of the metal itself, though it is never found in a native metallic state; and if all the aluminum in the compounds were recovered, it would be found, so it is estimated, to compose as much as one-twelfth part of the bulk of the earth.

With all this wide prevalence of the compounds, and a recognition of the value of the metal, no commercially satisfactory means of recovering it from the compounds were devised until very recent years, when certain electrical processes came into use. The process which is now universally used was almost simultaneously discovered in 1886 by Hall in the United States and Heroult in France.

Aluminum cannot be electrolytically deposited from solutions of its salts in water, as the metal at once becomes oxidized at the cathode, and some other solvent must be used. In the process of Hall and Heroult this solvent is a melted "bath" of the mineral *cryolite*, and the aluminum compound which composes the electrolyte in this bath is an oxide of aluminum, or *alumina*. Fortunately for the process, beds of a reasonably pure, natural aluminum oxide called *bauxite* are found in several parts of the world. Alumina is also a "by-product" of some chemical manufacturing processes.

In the operation of the process, melted cryolite is put into large iron pots which are lined with a hard, baked carbon mixture, and carbon anodes are dipped into the bath. The carbon lining of each pot serves as cathode. An electric current of about 2500 amperes is passed through each bath, with a pressure between the terminals of each pot of eight or nine volts. This represents sufficient power to heat the bath and keep the cryolite in a molten condition.

The aluminum oxide is dissolved in this bath of molten cryolite, and the electric current causes it to separate into its constituents — aluminum and oxygen. The aluminum goes with the current to the cathode, and lies in a melted condition in the bottom of the pot until siphoned off. The oxygen goes to the positive pole or anode, and combines with the carbon, which is gradually consumed. After the melted aluminum has been drawn off from the pot, it is cast into ingots, from which it may be made into sheets, rods, wires, or other forms, as may be desired.

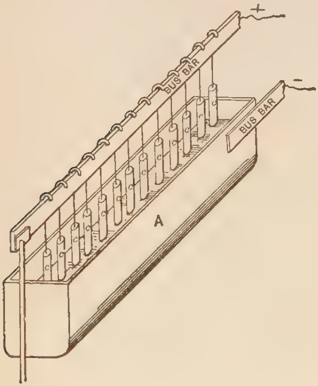

FIG. 333. — Vat used in the Recovery of Aluminum from Alumina. *C*, *C*, *C*, Carbon Anodes suspended in Bath of Molten Cryolite; *A*, Iron Crucible which contains Bath, and serves as Cathode.

Many thousands of horse power are used in the manufacture of aluminum at Niagara Falls, and equally great powers are utilized elsewhere in the world; and the demand for the metal is growing with a truly wonderful rapidity as the price becomes more reasonable. The cheapest aluminum ore, clay, has not been made available for use by any process of recovery yet discovered.

The direct current must be used in this process, as in other electrolytic processes; and where alternating current is supplied, as at Niagara by the Niagara Falls Power Company, it must be transformed into direct current by means of rotary transformers before it can be used in the electrolytic process. One of the electrolysis vats used by the Pittsburg Reduction Company for the production of aluminum at Niagara Falls is illustrated in Figure 333.

**384. Smelting by the Electric Arc.** — The electric arc, such as is seen in arc lamps, but very much larger, has been successfully used in working ores and producing chemical changes. This application is usually called **Electric Smelting.** The action which occurs in electric smelting is mostly due to chemical action set up by the intense heat of the electric arc which melts the ores. It was by electric smelting from corundum and similar material that the Cowles Company, of Lockport, N.Y., made the aluminum which was found in their formerly well-known aluminum bronze.

In the process of electric smelting, the ore, generally mixed with carbon, is placed between great carbon electrodes in a carbon-lined furnace built out of fire-brick, or composed of an iron box.

A current of hundreds, or perhaps thousands, of amperes is sent between the electrodes, and the heating is so violent that the ore is fused, or even volatilized, with an accompanying vigorous chemical action.

The first use of the high temperature obtainable by the electric arc for chemical purposes seems to have been made in some experiments by Depretz in 1849. Although several furnaces were made soon after, the real impulse to this line of investigation was given in 1880 by a paper of Sir William Siemens describing his own work.

The importance of the resulting developments cannot be well overestimated. They have already given us calcium carbide, from which acetylene gas is produced, carborundum, which is the hardest manufactured substance, and many other compounds which hitherto could only be manufactured at a prohibitory cost.

**385. Calcium Carbide.** — Calcium carbide, which is used for charging the acetylene generators used for lighting purposes, is made by electric smelting. In 1892, Moissan, in France, wrote: "If the temperature of the electric furnace reaches 3000°, the material of the furnace itself, the quick-lime, melts and runs like water. At this temperature the carbon rapidly reduces the oxide of calcium (lime), and the metal (calcium) is set free in abundance. It combines easily with the carbon of the electrodes to form carbide of calcium, fluid at this heat, which is easily recovered." This statement gave to the world the discovery of a valuable process for which Moissan probably deserves full credit, though Thomas L. Wilson, of the United States, is supposed to have made the discovery at about the same time.

To make the carbide, powdered lime and coke are thoroughly mixed and placed in an electric furnace similar in principle to that described in the previous article. When the mass is brought to a sufficiently high heat, the calcium of the lime combines with the carbon, forming calcium carbide. This carbide, when put into water, decomposes, and acetylene gas is formed.

**386. Carborundum.** — This product of the electric furnace takes a place with emery and corundum as a grinding and abrading material on account of its extraordinary hardness. It is a chemical combination of carbon and silicon, called silicon carbide, which is made in the electric furnace by fusing a mixture of clean sand and powdered carbon. Upon cooling the furnace, the carborundum is found in beautiful masses of lustrous, dark crystals. The character of the furnace used in its manufacture does not differ greatly from that described in the preceding article.

**387. Miscellaneous Applications.** — The applications of electrolytic processes and electric smelting are becoming very widespread, and are rapidly taking on an aspect of the utmost value. Electrolysis is being used in the large cotton mills and paper mills for the production of bleaching solutions; it is used in certain establishments for cleaning metal products, and, on the whole, its value as a process in manufacturing has apparently only begun to be appreciated, and the most rapid extension of its use may be confidently predicted. The rapid extension of electric smelting to the treatment of numerous metal ores and the manufacture of additional chemical products may be anticipated with equal confidence.

**388. Electric Forging.** — In some of the preceding articles it has been shown that the heat that may be developed from electrical sources is of great service in metallurgy. It is also applied in many simple processes, such as welding metals, cooking, etc.

The use of the electric current for heating and working metals is not new. As early as 1865 patents were issued relating to the subject; but on account of the great expense of the current generated by batteries, these early endeavors came to naught, and not until within a very few years has electric metal working been made an actual success. It was as late as 1888 before electric welding was applied to commercial uses, but immediately upon its introduction it came rapidly into favor, and even created much excitement among some manufacturers.

Electrical methods are now used for welding, brazing, heating, shaping, and tempering metals. For most of these purposes the method in common use is to pass an electrical current of very great volume through the metal to be worked. This great current generates sufficient heat as it passes through the resistance of the metal to quickly raise the temperature to a welding or bending heat, or even to melt the metal. This method of heating has an advantage over the ordinary method of heating in the forge fire, which heats a piece of metal from the outside, while the electrical method heats all parts of the metal equally and at the same time the metal remains perfectly clean.

The apparatus which is used for heating usually consists of an alternating current transformer, which reduces the line pressure of an alternating current to one or two volts, or even less, and increases its volume proportionally.[1] A welder transformer is shown in Figure 334. The grooved copper casting shown in the figure is the secondary coil of the transformer, which has only one turn. The primary winding, made up of numerous turns of wire, is intended to lie in the groove of the secondary, while the core, which is seen enclosing one side of the secondary casting, embraces both coils. At the top of the secondary casting are sliding clamps in which the metal to be heated is fastened.

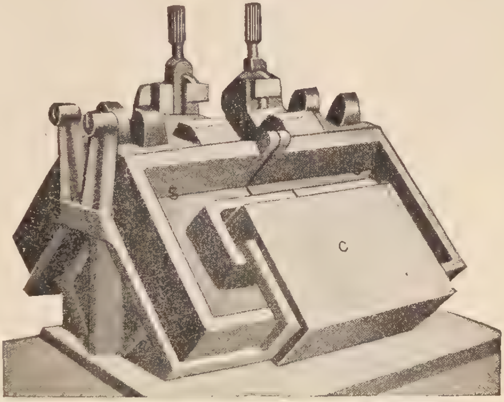

FIG. 334. — Alternating Current Transformer of Thomson Electric Welder. *S*, *S*, *S*, Copper Secondary Coil; *C*, Laminated Core of Transformer.

Electric welding, as ordinarily carried on, consists of heating, by the process above described, the pieces of metal to be welded while they are firmly butted against each other. When the metals have been heated till they are soft at the points in contact, they are squeezed together a certain amount, the current is shut off, and the weld is complete. This is the process developed so usefully by Professor Elihu

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[1] Article 239.

Thomson. The apparatus which is generally used in the Thomson welding process is: 1, an alternator, usually giving a frequency of from 40 to 60 periods per second; 2, a welding transformer with clamps (Fig. 334) and arrangements for automatically making the welds; 3, apparatus for controlling the amount of current supplied to the transformer.

Figure 335 shows a complete Thomson welder. The transformer is seen in the centre of the case, and the clamps on top. The weights at the left are for squeezing together the heated rods held in the clamps, and the relay shown at the right-hand side of the transformer is for cutting off the current when the weld is completed. In welding heavy work, hydraulic pressure is used to squeeze the weld.

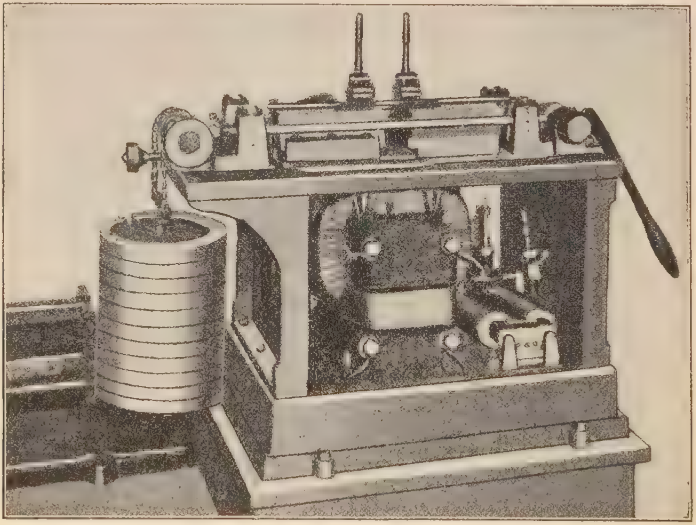

FIG. 335. — Thomson Automatic Electric Welder.

Many metals may be welded by the electrical method which cannot be coaxed into a weld by the ordinary methods of the blacksmith. Metals which have been welded by the Thomson process are named in the accompanying table: —

Wrought Iron.
Cast Iron.
Malleable Iron.
Various grades of Tool Steel.
Various grades of Mild Steel.
Steel Castings.
Chrome Steel.
Wrought Copper.
Cast Copper.
Lead.
Musshet's Steel.
Stubb's Steel.
Crescent Steel.
Bessemer Steel.
Tin.
Zinc.
Antimony.
Wrought Brass.
Cast Brass.
Gun Metal.
Brass Composition.
Cobalt.
Nickel.
Bismuth.
Fuse Metal.
Type Metal.
Solder Metal.
German Silver.
Silver.
Platinum.
Aluminum alloyed with Iron.
Aluminum Brass.
Aluminum Bronze.
Aluminum.
Phosphor Bronze.
Gold (pure).
Manganese.
Magnesium.
Silicon Bronze.
Coin Silver.
Various grades of Gold.

Again, many of these metals may be welded to each other in combination. The combinations which have been made are shown in the table below. In each of the cases where a weld can be made at all, it becomes practically as strong as the metal itself.

### COMBINATIONS

Copper to Brass.
Copper to Wrought Iron.
Copper to German Silver.
Copper to Gold.
Copper to Silver.
Brass to Wrought Iron.
Brass to Cast Iron.
Tin to Zinc.
Tin to Brass.
Brass to German Silver.
Brass to Tin.
Brass to Mild Steel.
Wrought Iron to Cast Iron.
Wrought Iron to Cast Steel.
Wrought Iron to Mild Steel.
Wrought Iron to Tool Steel.
Gold to German Silver.
Gold to Silver.
Gold to Platinum.
Silver to Platinum.
Wrought Iron to Musshet's Steel.
Wrought Iron to Stubb's Steel.
Wrought Iron to Crescent Steel.
Wrought Iron to Cast Brass.
Wrought Iron to German Silver.
Wrought Iron to Nickel.
Tin to Lead.

A very striking application of electric welding has been adopted by at least one manufacturer for welding together the parts of street railway track material, such as switches, frogs, etc., which are ordinarily made up by bolting together pieces of rails cut to proper shape. By the welding process bolts may be dispensed with, and the work, therefore, is made much more substantial. A process has even been developed for welding the rails of a street railway track together, thus doing away with the usual bolted joints which cause so much roughness in the track and require such a large expense for repairs. Figure 336 shows a track-welding outfit. This welder is arranged to work on track which is in place in the street. The current is supplied to it by a rotary transformer which transforms the 500-volt continuous current taken from the trolley wire into an alternating current at a pressure of about 350 volts. Figure 337 shows a complete weld at a rail joint. As much as 250 horse power is required for a few seconds in making such a large weld.

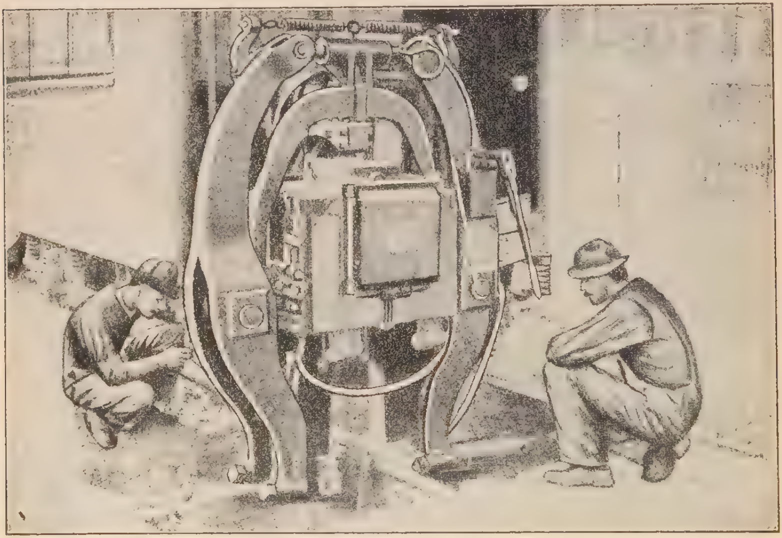

FIG. 336. — Electric Welder welding the Joints in Street Railway Rails.

**389. Welding a Ring.** — One of the striking things about Thomson electric welders, is their ability to weld up rings; and the welders may therefore be used in welding wagon tires, chain links, etc. In this case, the question occurs, "Why does the electric current not flow around through the solid metal from clamp to clamp, instead of through the path where the ends of the ring butt against each other?" This is simply a question of electrical impedance.[1] In the case of a wagon tire, the alternating current furnished by the welder transformer would have to flow through a path several feet long in going from clamp to clamp through the solid metal, while the path through the point to be welded is only a few inches in length, so that the latter path is of much the least impedance, and nearly all of the current follows it. The long part of the tire, being almost a complete turn, will have a large back pressure set up in it due to its self-inductance. In a very small ring, enough current may pass between the clamps through the solid part of the ring to heat it red hot, but that does not interfere with the welding.

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[1] Article 236.

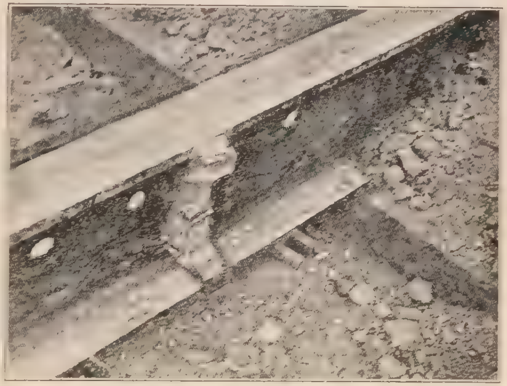

Fig. 337. — Welded Joint in Street Railway Track.

**390. Softening Armor Plate.** — An interesting application of the Thomson process has been lately made to softening, at points where bolt holes must be drilled, the very hard nickel-steel armor plates which are made for United States men-of-war. The plates are so hard that it is almost impossible to drill them as they come from the steel works, but by means of an electric heating arrangement they are softened at the spots where the bolt holes must be made, without injuring the temper of the other parts of the plates.

**391. Arc Welding.** — Another process of utilizing the heating effect of electricity for the purpose of welding and working metals, is that known as the **Arc Process**. This was first used by De Meritens, a Frenchman, and was later more fully developed by a Russian named Bernardos. In this process, a continuous current is used at a pressure of about 150 volts, one terminal of the electric generator being connected to the metal which it is desired to heat, and the other terminal being attached by a flexible conductor to a portable carbon rod (Fig. 338). When the carbon rod is brought against the work, an electric arc is set up and the metal is heated.

This device has been used in the process of filling with metal the blow holes which sometimes occur in valuable castings. It has also been used for welding the seams in small iron boilers, receivers for compressed air, and other iron vessels. It is of special advantage for the latter work, since the arc can be slowly drawn along the edges of the plates to be welded, thus bringing them to a welding heat, and the weld is then completed by pressing or hammering the edges together.

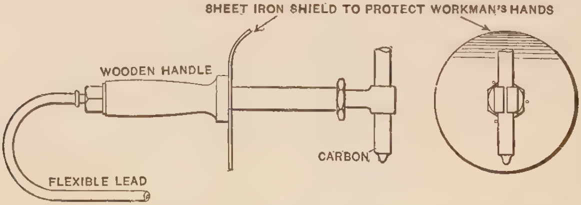

FIG. 338.—Carbon Rod mounted on Handle, with Protecting Shield for Use in "Arc Process" of working Metals.

**392. Pail Welding.**—In each of the methods of electric welding it is to be noticed that the electric current is used only for the purpose of heating the product previous to welding, and that the mechanical pressure required to complete the weld is applied by external means of some kind. There is another striking and even startling method of electrically heating metals for purposes of working them. If a pail of water, in which is dissolved some common washing soda, has immersed in it a lead plate which is connected to the positive terminal of a 150 or 200 volt electric circuit, it gives all the apparatus necessary for quickly heating iron. The metal to be heated is grasped in tongs which are electrically connected to the negative terminal of the electric circuit, the handles of the tongs being insulated.

When the metal is plunged into the pail of water, it is quickly brought to a white heat and may then be withdrawn and worked on the anvil or welded to another piece of heated iron by the ordinary blacksmith's method. Any metal may be heated by this process, but welding can be performed only on those metals which, like iron, can be welded by the blacksmith. The heating of the metal when it is plunged into the water, is apparently caused by an electric arc which is set up around the submerged metal on account of its becoming surrounded by a coating of hydrogen gas. The amount of current used varies from a few amperes to many hundreds, depending upon the size of the metal to be heated. It is a remarkable sensation to see *a piece of metal which is dipped into a pail of water come quickly to a blinding white heat;* and, when held in another pair of tongs (not connected to the electric circuit), to see *the same piece of metal again dipped in the same water for the purpose of cooling it.*

FIG. 339. — Common Form of Electric Heater.

**393. Cooking by Electricity.** — The direct heating effect of an electric current as it passes through resistance coils is now applied to the ordinary purposes of warming and also to cooking. Figure 339 shows one of the various forms of electric heaters, all of which simply consist of resistance wires embedded in an insulating material. These heaters are used quite generally for warming electric cars, and are coming into more or less use in other situations. Electric tea-kettles, which are kettles with an electric heater in their base, are not uncommon. Electric flat-irons, curling irons, soldering irons, and similar devices are slowly making their way into some use in towns where incandescent electric light circuits are at hand to supply the necessary current. In Figures 340, 341, and 342 are shown an electric sauce-pan, an electric curling-iron heater, and a smoothing iron.

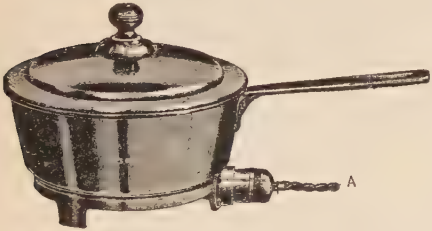

FIG. 340. — Electric Sauce-pan. *A* is a flexible conducting cord which may be extended for connecting the sauce-pan with an electric circuit.

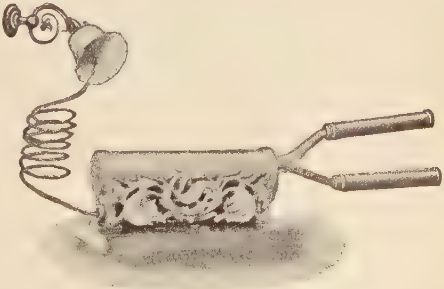

FIG. 341. — Electric Curling-iron Heater with Curling Iron.

Whole electric kitchen outfits may be obtained, including an electric range, and they are sure to come into quite common use if their cost becomes reduced to about that of coal ranges. The arrangement of a complete kitchen outfit is shown in Figure 343.

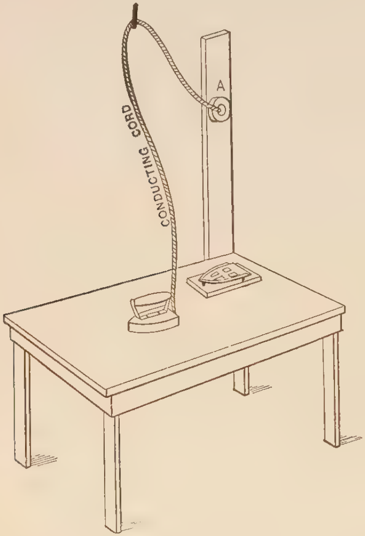

FIG. 342. — Electric Smoothing Iron. *A* is point of attachment of the conducting cord to the electric circuit.

While electric cooking may be said to be satisfactory on account of its convenience, cleanliness, and adaptability, electric heating for general purposes can never replace the direct use of coal or the use of steam heating, until electricity is directly generated from the fuel or its equivalent without the intervention of steam engines in which enormous losses of heat cannot be prevented. The nature of steam engines makes it impossible, even with the best of them, to convert into useful power more than 10 or 15 per cent of the heat energy contained in the coal which is shovelled into the boiler furnace. When the steam generated by the boiler is directly used for heating, a very much greater proportion of the heat in the coal is converted to a useful purpose; in fact, this proportion may be so great as to lie between 60 and 80 per cent.

## QUESTIONS

1. What is electroplating ?
2. What metals are generally used in plating ?
3. What is the history of electrometallurgy ?
4. What is the salt of a metal ?
5. What is nitrate of silver ? Cyanide of silver ? Cyanide of potassium ?
6. How may nitrate of silver be made ?
7. What kind of vats are usually employed in silver plating ?
8. Why must the anodes in a plating vat be of the same metal as the plate which is deposited ?

9. Why is nitrate of silver not used for silver plating solutions?
10. What is the best solution for silver plating?
11. How may cyanide of silver be made?
12. Upon what does the quality of the electrolytic deposit of a metal depend?
13. What is the effect upon a silver deposit when the current is too great and when it is too small?
14. How are articles cleaned before plating?
15. How are the insides of silver articles gilded?

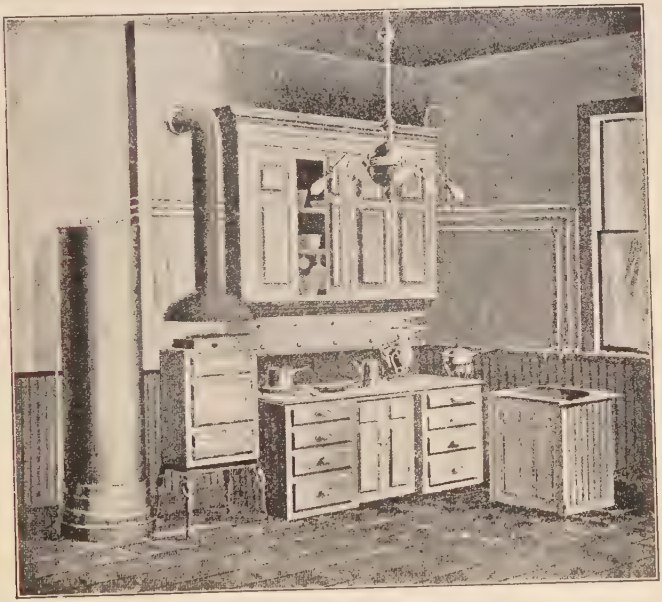

FIG. 343.—Electric Kitchen Outfit.

16. Upon what base metals is nickel usually plated?
17. Why is nickel used instead of silver for plating articles which will receive hard usage?
18. What solution is used for nickel plating?
19. What effect on nickel plating is caused by the presence of organic impurities in the bath?
20. For what purpose is electrotyping used?
21. Why are electrotype moulds plumbagoed?

22. How is an electrotype finished after the copper shell has been deposited ?

23. How thick should the copper shell of an electrotype be ?

24. What are the advantages of electrolytic refining of copper ?

25. What solution is used in electrolytic copper refining ? What is crude copper ?

26. What materials may be looked upon as crude ores of aluminum ?

27. What is the process for refining aluminum ?

28. When was electric smelting by the arc first done ?

29. How is calcium carbide made ?

30. What is carborundum ?

31. For what kinds of metal working are electric forging methods used ?

32. What is the most common method of electric forging and what are its advantages ?

33. Describe the Thomson welder.

34. What metals may be welded by the Thomson method ?

35. How is it that rings may be welded by a Thomson welder ?

36. What is the Bernardos process of working metals ? What is it used for ?

37. What is a pail welder ?

38. What happens in a pail welder when it is working ?

39. How is the heating effect of the electric current used for warming and cooking ?

40. Why cannot electric heaters at present replace stoves ?

# CHAPTER XXIII

## ELECTROMAGNETIC WAVES; WIRELESS TELEGRAPHY; ROENTGEN RAYS

**394. Water Waves or Vibrations.** — When a pebble is thrown into a pond, waves of water ripple away in ever widening circles, and the waves travel outward in all directions along the surface of the water from the place where the pebble strikes. The crest of each wave travels onward until it is either broken upon some obstruction, as the pond banks, or is dissipated by the friction of the water itself, when its height becomes so small as to be no longer discernible. The distance between the crests of two adjacent waves is called the **Wave Length**, while the difference in level between the crest and trough is called the **Amplitude** of the wave (Fig. 344).

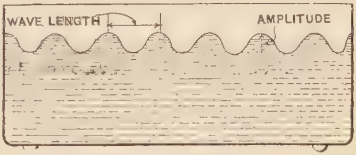

FIG. 344. — Illustration of Amplitude and Wave Length of Waves on the Surface of Water.

If a log lies in the pond, the waves will break upon it and leave comparatively still water on its farther side (thus creating what may be called a water-wave shadow), though the waves which pass the ends of the log will tend to spread out and fill the shadow space.

If a second set of waves is created, they may interfere with the motion of the waves of the first set by striking against them, and the waves of the two sets then become entangled and broken up. This is called **Interference** of the waves. However, if the water is struck at regular intervals by a rod or a paddle, a certain rate of strokes may be found which will produce a series of waves which do not interfere, but which move off regularly and strongly. It will also be found that the wave length is dependent upon the force and character of the stroke.

Although these water waves move out rapidly from the centre of disturbance, the particles of water merely move up and down, and do not flow away from their position in the pond. That is, the water is set to **Vibrating** (or swinging up and down), but not to flowing. This may be proved by observing a chip or leaf which has been thrown into the pond, when it will be seen that the float merely vibrates up and down as the waves pass it, and (if the wind does not interfere with it) it does not change its position in the pond, as it necessarily would if the water actually flowed along with the waves.

When the vibration of the particles of a body is at right angles to or across the direction of the movement of the waves, as is the case with the water waves, it is called **Transverse Vibration**. If, on the other hand, the particles vibrate along the line of the waves instead of across it, the vibration is said to be **Longitudinal**. The vibrations of a stiff spiral spring, which has been compressed endwise and then released, are longitudinal vibrations. Figure 345 illustrates a spring which is designed to be struck by a hammer. When the spring is struck, waves of compression pass very rapidly from the top to the bottom of the spring, while any part of the spring will merely vibrate back and forth. The waves in the air that we call **Sound Waves** are waves in which the vibration of the particles is longitudinal. When one utters a sound, spherical-shaped waves of alternately compressed and rarefied air radiate away from the speaker (as the waves of water radiate from a point of disturbance), but the air particles vibrate back and forth, longitudinally, in lines parallel to those of the waves they create.

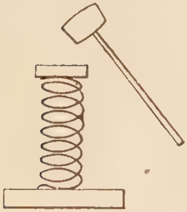

FIG. 345. — Spiral Spring which may be struck by Hammer to illustrate Longitudinal Vibration.

**395. Ether Waves or Radiation.** — Waves that can be seen and heard in the ordinary way have the same wave characteristics as those that are supposed to be set up in the **Ether** when light, electrical energy, or magnetic disturbances are transmitted. We cannot conceive of light and heat coming from the sun without some medium for transmitting them. The air is supposed to extend only a few miles beyond the earth's surface, and the sun is millions of miles away, so that the air cannot be the required medium. It is believed, therefore, that there is some other substance which serves for the transmitting medium. This substance is called **Ether.**[1]

The ether is not supposed to be matter, as we usually consider it; but is assumed to have the capability of being set into vibrations or wave motions, much as a plate of jelly may be caused to vibrate by gently striking it at any point. The ether is thought to pervade everything and to be everywhere. Ordinary matter, such as our bodies, is supposed to be made up of separated molecules or atoms, and the ether is all about, between, and perhaps through these particles. When we move about in ether we do not disturb it. We move through it, as the ghost of the story books is supposed to pass through walls and other obstructions that are impervious to us.

Although materials can be moved from one place to another without disturbing the ether, yet it may be set vibrating if an object is heated. When a body is heated, its particles are thought to be set into rapid vibration, and this sets up corresponding waves in the surrounding air and ether. When you hold your hand toward a hot object, your hand feels the warmth. This feeling is caused by the mechanical heat waves in the air striking against your hand. If the body is heated until it is white hot, ether waves of shorter lengths are generated by the vibrating particles, and these cause the sensation of light when they strike against the retina of the eye.

Ether waves can also be generated by electric or magnetic disturbances. When these waves strike conductors at a distance, electrical activity is set up in them. This is now believed to be the medium of electromagnetic induction.[2]

A very crude mechanical analogy of electromagnetic induction may be constructed by sticking two pins in a plate of jelly (Fig. 346). Now, if one pin is struck and caused to vibrate, a wave is set up in the jelly which starts the other pin to vibrating in the same way. In this way mechanical energy is transmitted by the jelly waves from one pin to the other.

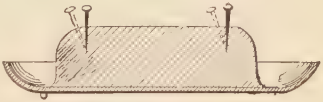

FIG. 346. — Jelly Analogue of Electromagnetic Induction.

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[1] Article 2.

[2] Article 132.

Or we may compare the effect of the ether waves to the sound waves which may be set up in the air. When a person speaks, waves are set up in the air which strike upon the ear drum, causing it to vibrate; thus, in turn, exciting the nerves of hearing. Again, if one floating block is caused to swash up and down in the water so as to set up waves in the pond, another float in an adjoining part of the pond receives an up and down motion when the waves reach it.

The ether waves vary in frequency from several thousand trillion periods per second to, possibly, one hundred million periods per second, or less; and the wave lengths vary from a few millionths of an inch in length (from crest to crest) to several feet or yards in length. The waves all travel, so far as is known from experimental investigation, at a speed of about 186,000 miles per second. This distance is almost seven and a half times the circumference of the earth. The ether waves of shortest known wave length can be detected only by the chemical action they produce when they strike upon certain substances; some longer waves are perceived by the eye, as light; still longer ones become apparent from their heating effect; and the longest create the electromagnetic phenomena with which we are to deal in the following articles.

**396. Electromagnetic Waves.** — In 1864, Clerk Maxwell, one of the most gifted mathematicians of the world's history, showed by a brilliant mathematical demonstration that it ought to be possible to create ether waves by electrical disturbances.[1] The experimental proof of Maxwell's mathematics, however, was not forthcoming until 1888, when Heinrich Hertz, a German investigator, actually produced such waves by an equally brilliant investigation, but this time carried on in the laboratory. He created electromagnetic waves by passing sparks from an induction coil through a gap between two polished knobs. An apparatus for the purpose, which is called an **Oscillator**, is illustrated in Figure 347. In this figure, *A* is an induction coil for getting a high pressure, and *B* is the spark gap.

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[1] It must be remembered that the characteristics of the ether, and even its existence in the particular form in which we conceive it, are purely theoretical hypotheses, the truth of which has not yet been proved. But experiments relating to electromagnetic radiation and allied phenomena go far toward justifying our acceptance of the ether theories. In any event, these theories enable us to gain a reasonably clear physical conception of various occurrences, such as those described in this chapter, which we might not otherwise be able to grasp; and the experimentally demonstrated facts will always be ours, even if the particular characteristics which we now ascribe to the ether are partly swept away by the advance of experimental science.

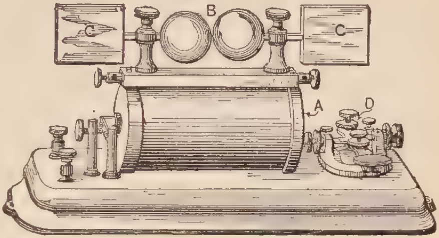

FIG. 347. — Transmitter for Wireless Telegraphy. *A*, Induction Coil; *B*, Spark Gap; *C*, *C* Condensers; *D*, Telegraph Key.

When a spark passes across the gap, *B*, it looks like a single flash, but in reality the electric discharge flies back and forth across the gap many times with inconceivable rapidity (possibly at the rate of one hundred million times per second, or even more). This makes a rapidly vibrating or alternating current which gradually dies out, as illustrated in Figure 348. The effect is analogous to the mechanical action of a spiral spring which has been compressed and then released. When the balls are charged to a high difference of pressure, we may consider that the medium surrounding the balls, which is called the dielectric,[1] is under an electrical pressure or stress; and the passing of the rapidly vibrating spark occurs when the dielectric is relieved by the spark breaking through, and the electric current surges back and forth like the spiral spring when it is released.

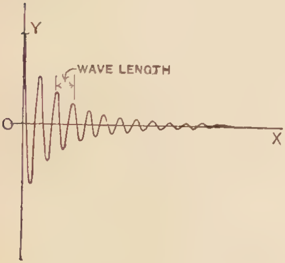

FIG. 348. — Chart of Oscillatory Electric Discharge.

Now these vibrations of electricity, which really pass through the entire apparatus, are capable of setting up waves in the ether which pass out in all directions, but more strongly in a direction at right angles to the spark gap and the wings *CC* (Fig. 347). The ether waves which are created in this manner are called **Electromagnetic Waves.** To detect these waves, Hertz used a ring of wire containing a small spark gap, such as is shown in Figure 349. When this **Resonator,** as it is called, is held so that the ether waves pass through the ring, electrical vibrations are set up in the ring and are indicated by small sparks passing across the air gap. The effect of the oscillator on the resonator may be compared to two tuning forks of the same pitch which are placed at a distance apart. When one fork is set to vibrating, the air or sound waves beat upon the other and set it also to vibrating. This may be perceived by carefully examining the second fork a short time after the first fork is set to vibrating, when it may be readily noticed that the second fork is vibrating.

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[1] Article 28.

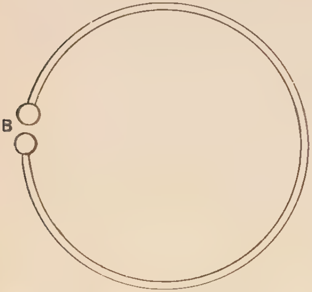

FIG. 349.— Hertzian Resonator or Ether Wave Indicator. *B*, Spark Gap.

It is necessary to have the two forks of the same tone or musical note to get this effect in its fullest power. The second fork vibrates because the sound waves beat upon it at a rate which is equal to the natural rate of vibration of the fork, and each impulse from the sound waves adds to the preceding impulses. And just so it is necessary to have the electric oscillator and resonator tuned together, so that the resonator may naturally respond to the *ether waves* projected upon it by the oscillator in a manner that is analogous to that with which the second tuning fork responds to the *sound waves* projected upon it by the first fork. If one swings in a hammock, it is desirable to give the pushes which cause the hammock to swing (vibrate) at the same rate at which the hammock is going back and forth. If the pushes are given at any other rate, they tend at intervals to stop the motion and at other intervals to help it; that is, there is *interference*.

The natural rate of electrical vibration of the resonator or oscillator is dependent upon the dimensions of the conductor composing the instrument, and an adjustment may be effected by changing the sizes of the wings, *CC*, on the oscillator (Fig. 347), or the resonator ring (Fig. 349), until their rates or frequency are the same.

It has been learned by experiment that the electromagnetic ether waves can be **Reflected, Refracted, Polarized**, etc., just as can light waves or heat waves, which clearly indicates the close alliance of the different kinds of radiation.

**397. Wireless Telegraphy.** — The ether waves may also be detected by what is called a **Coherer** (Fig. 350). In the figure, *A* is a small glass tube with metal rods projecting into it at either end, but between the ends of which there is a small space. This space at the centre is partly filled with metal filings, preferably of silver. The electrical resistance through these filings is ordinarily several thousand ohms, but when properly tuned ether waves from an oscillator strike upon the tube, the filings **Cohere**, or stick together, thus reducing the resistance to a very few ohms. The cause of the cohering is supposed to be due to the particles of the filings being drawn together by electrostatic or electromagnetic attractions set up between them.

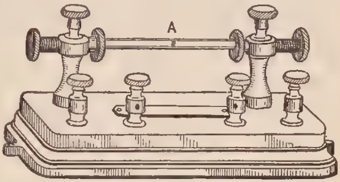

FIG. 350.—A Coherer by Means of which Ether Waves may be detected.

If the circuit of a battery (composed of a cell or two) and a relay[1] is completed through the coherer by making connections to the two metal rods at the ends of the coherer, the relay may be so adjusted that it will only work when the resistance of the circuit is lowered by the coherence of the filings. If the relay is made to work a local circuit containing a sounder,[2] this sounder will click whenever the proper waves from an oscillator strike the coherer.

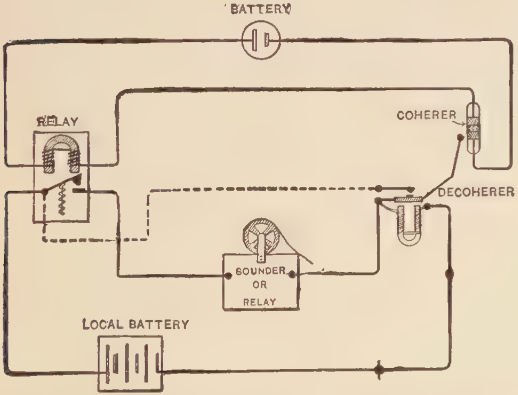

FIG. 351. — Diagram of Wireless Telegraph Receiving Station.

After the filings have once cohered they will remain so unless they are shaken apart; therefore, a second electromagnet is usually placed in the local circuit which contains the sounder, and this magnet is so arranged that whenever a current passes through its coils its armature is caused to strike against the glass tube, and thus **Decohere** the filings by giving them a sudden jar. Figure 351 shows the connections of the circuit. Now, if a key is used for opening and closing the primary circuit of the induction coil in an oscillator (as shown at *D* in Figure 347), telegraph signals may be transmitted by means of the ether waves, which may be received and recorded by a receiving apparatus like that just described. Telegraphing by such means is usually called **Wireless Telegraphy**, since the signals traverse space by means of the ether waves and without the intervention of wires. Figure 347 shows a commercial transmitter for wireless telegraphy, and Figure 352 shows a suitable arrangement of the receiving apparatus. Figure 353 is a diagram of receiving and transmitting stations ready for operation.

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[1] Article 299.

[2] Article 298.

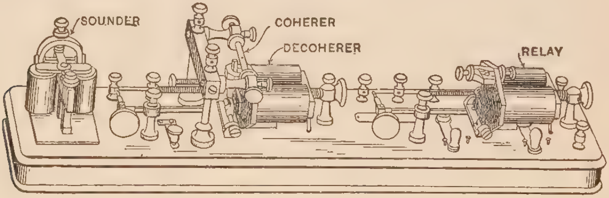

FIG. 352. — Receiving Apparatus for Wireless Telegraphy.

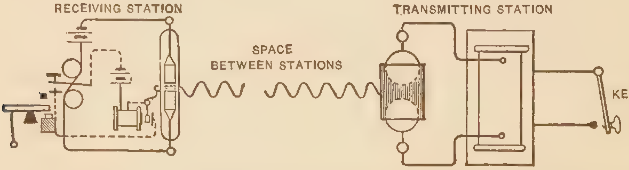

FIG. 353. — Diagramatic Illustration of Transmitting and Receiving Stations for Wireless Telegraphy.

Where the distance between the transmitting and receiving stations is great, one terminal of the coherer and one of the oscillator are connected to earth, and the other respective terminals are connected to wires that run a hundred or more feet vertically into the air. A light plate of metal is usually attached to the upper end of each of these wires.

William Marconi, an Italian, has succeeded in transmitting messages a distance of sixty miles by the means described. The signals can be transmitted through hills and walls with success, for the materials comprising them are transparent to the electromagnetic ether waves, just as glass and mica are transparent to light waves.

**398. Cathode Rays.** — There are many other phenomena which are supposed to be caused by waves or disturbances in the ether, and which may be created through electrical means. Professor Hittorf, of Germany, (in 1869), and later, Professor William Crookes (1874–1879), a celebrated English chemist, made valuable investigations on the effect of electric discharges through a vacuum.

If a closed tube or bulb of glass has two wire terminals, or *electrodes*, sealed into the glass and protruding within the tube in the way that is illustrated in Figure 354, a curious flickering light or glow is observed within the tube when the electrodes are attached to the terminals of an induction coil, provided the air has been previously exhausted from the tube after the manner of exhausting applied to incandescent lamps.[1] If the vacuum is poor, the light produced is of an even, delicate color throughout. If the vacuum is improved, the light near the terminal from which the current of the discharge leaves, which is called the *cathode*, becomes somewhat violet in color, while the remainder of the tube up to the other terminal, or *anode*, is filled with beautiful masses of changing and varying light. Crookes found that the glass of the tube itself apparently lights up by a peculiar, delicate light when the tube is very highly exhausted, — the color of the light depending upon the kind of glass (this state of the glass is called **Fluorescence**), — and then but little light is seen in the space within the tube, except for occasional flashes. It is supposed that these effects are the result of a phenomenon called **Cathode Rays**.

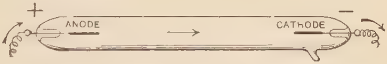

FIG. 354. — Simple Form of Crookes Tube.

Crookes found that if the cathode of the tube is made in the shape of a concave mirror, the rays meet at a point, and that they can be caused to heat a piece of metal located at the point to a white heat.

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[1] Article 256.

These rays apparently cannot be induced to come through the glass walls of the tube, but Dr. Philip Lenard in 1893, following a suggestion of Hertz, induced them to pass through an aluminum window which he inserted in the glass walls. Lenard discovered that these extensions of the cathode rays act upon a photographic film, and in other respects perform in a most remarkable manner.

It is now thought that the cathode rays consist of very minute flying particles of matter — much smaller particles than those we ordinarily conceive as atoms. These are presumably shot off from the cathode by some unknown electrical action, and travel away with a speed that is perhaps one-twentieth as great as the velocity of light. The flying particles, or "corpuscles," as they are named, carry negative charges of electricity. The explanation of their production and character is still very obscure and must remain little better than a happy guess until additional experimental knowledge of them is obtained.

**399. Roentgen Rays.** — William Konrad Roentgen took up the study of cathode rays in the fall of the year 1895. He then held the chair of physics in the University of Würtzburg in Bavaria, and was well known in Germany as an original experimenter in physical science. On Nov. 8 of that year he was experimenting with a well-exhausted Crookes tube (Fig. 354) which was covered by black cardboard, so that no ordinary light could pass from it to the room. Near by lay a sheet of paper covered with a chemical compound which shines when struck by ether waves of high frequency. Crystals of the tungstate of calcium possess this property, which is called **Fluorescence**. Professor

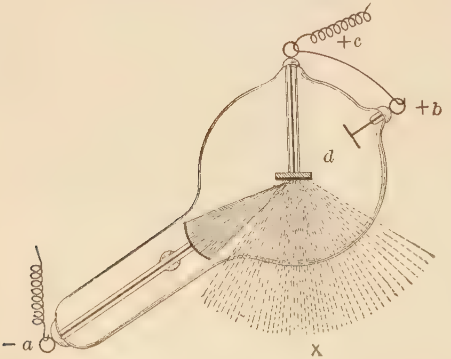

FIG. 355. – Typical X-Ray Tube. *a*, Cathode; *b*, *c*, Anodes; *d*, Metal Source of X-Rays; *X*, X-Rays.

Roentgen noticed a peculiar line occurring on this paper while the tube was working, which indicated that something like light proceeded from the tube and cast a shadow upon the paper. An investigation showed that the effect was due to an hitherto unknown radiation proceeding from the tube, and **Roentgen** or **X Rays** were discovered.

These rays or waves of Roentgen are apparently created where the cathode rays of a Crookes tube strike a solid object like the glass walls of the tube. If the cathode rays are focussed upon a bit of metal by a concave cathode, the Roentgen waves may radiate from the surface of the metal. Figure 355 shows diagrammatically the cathode rays focussed upon such a metal piece, and the X-rays, *X*, passing downward. The tube shown in the figure is of typical form, though they are now made of various sizes and shapes.

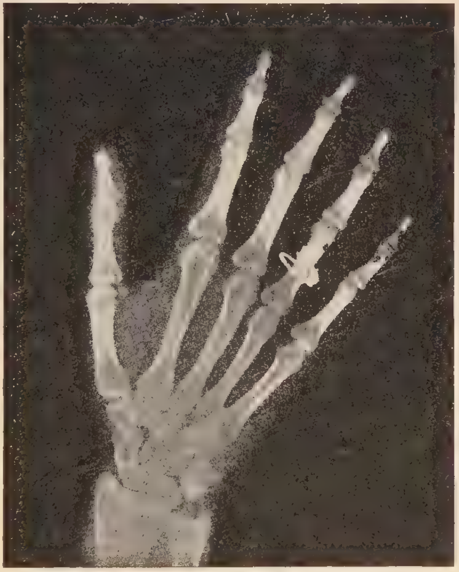

FIG. 356. — Radiograph of Hand with Gold Ring on Third Finger.

Roentgen found that different materials held between the working tube and a fluorescent screen — now called a fluoroscope — greatly differ in their transparency to X-rays. Heavy (that is, dense) metals or materials, such as zinc or iron, in general cut off the X-rays to a large extent, and thus cast a shadow on the fluoroscope, while light materials, like wood and aluminum, seem to be transparent to the rays, and to cast almost no shadow. When a hand is held between a fluoroscope and a tube, the denser bones cast a distinct shadow, and the flesh casts scarcely any. In the same way, silver money in a pocket-book casts a dense shadow, while the leather book casts very little; and nails driven into a wooden block make a black shadow, while the wood is light.

Having investigated the rays by the use of a screen, Roentgen tried a photographic plate and found that the rays affected it in the same manner as light. Therefore, when the hand is placed between the tube and the plate, a "radiograph" is taken of the bones, the less dense flesh parts showing very indistinctly, while the bones are clearly outlined. Figure 356 shows a "radiograph" of a hand, and Figure 357 shows one of a rat. The rays are nearly all stopped in their progress from the X-ray tube to the photographic plate by the denser bones, but the flesh is nearly transparent to the rays. Consequently, the photographic negative gives almost the appearance of a negative which shows a skeleton hand, or a skeleton rat, or other body. If the sensitive photographic plate is bought in paper wrappings, it is not necessary to remove them, as they are easily pierced by the rays. Figure 358 shows the complete apparatus for taking X-ray pictures which is used in hospitals, with its battery, induction coil, tube, plate, and operating chair. The patient is about to have a radiograph taken of the interior of his chest. Such photographs are taken for the purpose of locating fractures in the bones, extraneous metal objects, like bullets or needles in the flesh, and other similar purposes.

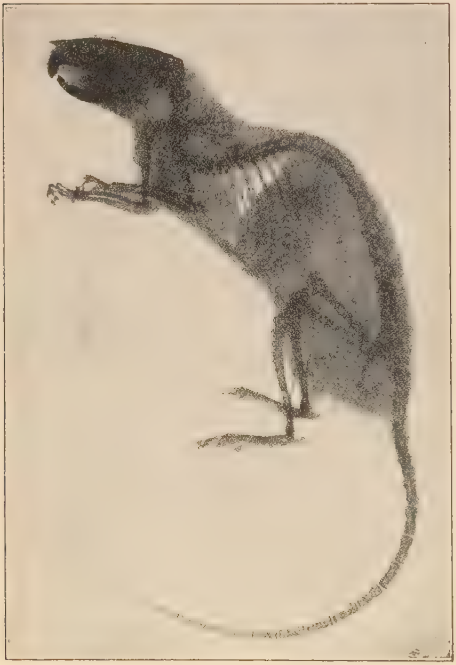

FIG. 357. — Radiograph of a Rat.

The true nature of Roentgen rays has yet to be determined, but it is competently suggested that they consist of waves or ripples, of very short wave length, started in the ether when the corpuscles of cathode rays collide with a solid object. We must, however, depend on the illuminating discoveries of the future to enable us to safely draw conclusions regarding the exact relations of these ether ripples to the ether waves called light, or the other ether manifestations called electricity and magnetism.

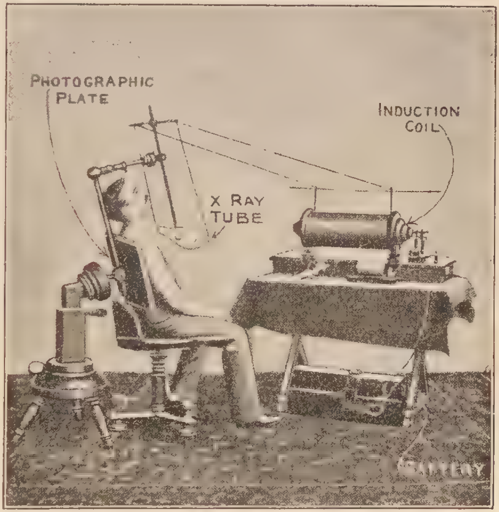

FIG. 358. — Radiographic Apparatus arranged for Use in a Hospital.

The lines of investigation considered in this chapter seem to be of narrow breadth, but they are apparently just touching the great field of knowledge that is to be ultimately opened to us, step by step, and which will perhaps cause the greatest industrial advances. The men whose names have appeared most frequently in this book — Gibert, Franklin, Ohm, Ampere, Volta, Faraday, Oersted, Davy, Henry, Maxwell, Crookes, Hertz, Roentgen, Kelvin, Siemens, Gramme — and many others, have each added a portion to the ever growing sum of man's knowledge of physical facts and laws. The advancement is steadily proceeding, and will surely continue to proceed. New discoveries based upon those grown old are continually recorded by the great band of investigators of the world. We know little of the laws of the universe, and much less of its fundamental structure. The study of electromagnetic phenomena seems to lead toward an unravelling of the unknown in nature. If we ever learn the true constitution of electric and magnetic phenomena, we may expect at the same instant to know the constitution of matter and the truth regarding the hypothetical ether. With such knowledge, the character of man's life may enter a condition of satisfaction and convenience exceeding our richest dreams. Many of our common mechanical necessities (the telegraph, the telephone, the electric light, the electric car) were lately almost inconceivable, and the adaptation of present known forces to man's use is only begun. New discoveries are also gradually bringing to us the possibility of new utilities of which we do not now conceive. And the twentieth century may be expected to exert the most beneficent influence on civilization through man's more intelligent and perfect application of nature's laws

## QUESTIONS

1. What is meant by the phrase, wave length ? The phrase, amplitude of a wave ?
2. When a pebble is thrown into a pond, does the water move with the waves ?
3. What is transverse vibration ? Longitudinal vibration ?
4. Give examples of transverse and longitudinal vibrations.
5. How is light transmitted ?
6. How can a piece of coal be made to create ether waves ?
7. Give mechanical and sound analogies to transmission of light and heat by ether waves.
8. How fast do ether waves travel ?
9. How long are ether waves ? What is their frequency ?
10. What did Maxwell point out in 1864 ? When did Hertz make his discovery ?
11. Give a mechanical analogy to an electric spark.
12. What is an oscillator ? A resonator ? How did Hertz use them ?
13. Why must an oscillator and resonator be tuned to work together ? Give a mechanical analogue.
14. What is a coherer ? How does it work ?
15. What is wireless telegraphy ? Describe the apparatus in detail and state the use of each part.
16. How can you telegraph through the walls of a building ? Why ?
17. What did William Crookes discover in 1875 ?
18. What happens when a spark is passed through an exhausted tube ?
19. What are cathode rays ?
20. What are Roentgen rays ? When were Roentgen rays discovered ?
21. How are Roentgen rays obtained ? How are radiographs made ?
22. Are light or dense substances pierced the more readily by Roentgen rays ?
23. To what use are Roentgen rays put in hospitals and by physicians ?

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